

THE MODULARITY OF AESTHETIC PROCESSING AND PERCEPTION
IN THE HUMAN BRAIN.
FUNCTIONAL NEUROIMAGING STUDIES OF NEUROAESTHETICS

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2007

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Abstract

By taking advantage of the advent of functional Magnetic Resonance Imaging (fMRI) this thesis argues that aesthetics belongs in the domain of neurobiology by investigating the different brain processes that are implicated in aesthetic perception from two perspectives. The first experiment explores a specific artistic style that has stressed the problem in the relationship between objects and context. This study investigates the neural responses associated with changes in visual perception, as when objects are placed in their normal context versus when the object-context relationship is violated. Indeed, an aim of this study was to cast a new light on this specific artistic style from a neuroscientific perspective.

In contrast to basic rewards, which relate to the reproduction of the species, the evolution of abstract, cognitive representations facilitates the use of a different class of rewards related to hedonics. The second part investigates the hedonic processes involved in aesthetic judgments in order to explore if such higher order cognitive rewards use the same neural reward mechanism as basic rewards. In the first of these experiments we modulate the extent to which the neural correlates of aesthetic preference vary as a function of expertise in architecture. In the second experiment we aim to measure the more general effects of labelling works of art with cognitive semantic information in order to explore the neural modulation of aesthetic preference relative to this information.

The main finding of this thesis is that stimulus affective value is represented separately in OFC, with positive reward (increasing aesthetic judgments) being represented in medial OFC and negative reward value is being represented in lateral OFC. Furthermore ventral striatum encode reward expectancy and the predictive value of a stimulus. These findings suggest a dissociation of reward processing with separate neural substrates in reward expectancy and stimulus affective value.

Acknowledgements

My years at the Wellcome Laboratory of Neurobiology have been the most demanding, challenging and educational of my life so far. There is a substantial group of unique people that I have been fortunate to meet and whom I owe considerable gratitude for my time at the Zeki lab. Beyond the structures of randomness and possibly a portion of faith which surely most have played its part in making the London-years possible I am deeply grateful to Professor Semir Zeki for initially taking me onboard the Zeki lab, for believing in my ideas, and his insistence in making me into a neuroscientist.

My eternal gratitude goes to my parents, Kirsten and Egon Kirk, for all they have provided of love and support to their children.

I have enjoyed many hours of stimulating conversations about neuroaesthetics with Henry Chase in various coffee shops at UCL and in the Bloomsbury area.

Jakob H. Kowalski has persistently shown me that there is more neuro to life than neuroscience, and shown me the value of an evolving friendship. A friend in need indeed!

Thanks to all at Vislab (in order of appearance); Andreas Bartels, Taiji Tarkanashi, Richard Lewis, Oliver Hulme, Matt Self, Barrie Roulson, Thomas Müller, John Romaya, Velia Cardin and Anton Budakov.

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PART 1

INTRODUCTION

1.1 Overview

This thesis is concerned with the brain's ability to form aesthetic judgments from a visual stimulus. It takes as its starting point the theory of functional specialisation in the visual system (Zeki, 1978). This theory proposes that the visual system is organised into multiple, parallel systems, which are specialised for processing particular attributes of the visual scene (such as colour, motion, form, faces etc.). This parcellation of function has subsequently lead to a *neuroaesthetic* theory of functional specialisation which proposes that there is not one aesthetic sense but many, each one tied to activity in a functional specialised visual processing system (Zeki, 1997, 1999). One category of neuroaesthetic studies derived from this theory may be characterized as exploring artistic currents with implication for perception of functional specialised attributes, such as kinetic art with implication for motion perception (Zeki & Lamb, 1994) and Fauvism with implication for colour vision (Zeki & Marini, 1998). In this thesis we have additionally concerned ourselves with a higher sense of aesthetics to which the individual functional specialised attributes of aesthetics is a prerequisite. This second category of neuroaesthetic studies in this thesis explores the subjective processes involved in the formation of aesthetic judgments. This raises the question if there are many aesthetic processing systems or a unified processing system that integrates information from each individual aesthetic system in making an aesthetic judgment. An aesthetic experience does not necessarily have a particular effect on our welfare and internal need state, (as in contrast to primary rewards), but it could easily generate a very rewarding visual experience. Do higher order cognitive rewards (such as aesthetic judgments) use the same neural reward mechanism and structures as the more basic primary rewards? In the cause of three fMRI studies we address these issues by incorporating results from both categories of neuroaesthetics.

The search for the source of beauty has been debated for at least 2500 years and has been given a wide variety of answers. One can broadly distinguish two main

positions. Many theorists, dating back at least to Plato, saw beauty as a property of an object that produces a pleasurable experience in any suitable perceiver (Tatarkiewicz, 1970). Other theorists, dating back at least to the Sophists, proposed that anything could be beautiful if it pleases the senses (Tatarkiewicz, 1970). Particular with Kant the emphasis shifted more to a search for the principles of beauty and aesthetic judgment in the perceiver (Kant, 1790). This thesis is an attempt to study the concept of beauty experimentally using functional magnetic resonance imaging (fMRI) with the primary aim to determine the cortical and subcortical mechanisms involved in the formation of aesthetic judgments. Indeed, a subtext in this thesis is to bridge the divide of the two cultures – famously delineated by C.P. Snow (1959) between the Sciences and the Humanities – from the perspective of neuroscience.

With the novelty of this discipline, named neuroaesthetics, and its underlying philosophical connotations implied in the concept 'aesthetics' it is deemed necessary to review and delineate the literature bearing on two factors. First, by tracing the genealogy of aesthetics in philosophical discourses. Second, by reviewing the neuroscientific literature relevant in a neuroaesthetic context. Arising from this historical review is evidence from psychophysics, electrophysiology, fMRI and neurology suggesting that the human brain may be equipped with a common system for assigning value to a stimulus among competing reinforcers. This suggestion is fortified by the results of the imaging studies given here.

1.2 Thesis structure

Firstly we experimentally addressed, whether the brain respond differential to the changes in visual perception due to a violation of the relationship between object and context. We used functional magnetic resonance imaging to measure brain activity when subjects perceived objects in normal contextual settings compared to when the same object is perceived in an abnormal contextual setting. We were

interested in exploring if brain areas that are activated when perceiving objects in normal conditions are also recruited when perceiving objects that are liberated from their expected and semantic context. To accommodate this aim we found it relevant to consult the paintings of the Surrealist painter Rene Magritte (1898–1967) who sought to give the object primacy by pursuing the relative relationship between the object and its context. Indeed, a second aim of this study was to cast a new light on this artistic current from a neuroscientific perspective in order to further pursue the development of neuroaesthetic studies that take advantage of specific artistic currents with implication for the visual brain as demonstrated in work from our lab using kinetic art (Zeki & Lamb, 1994) and Fauvist art (Zeki & Marini, 1998). We consider that the artist's ability to induce beauty in the mind of the viewer gives him a particular competence as a sensory neurobiologist, as well as artist (Zeki, 1999). Thus, we additionally incorporated how object–context relationships would modulate aesthetic judgments in the design.

The results of the first study revealed a cortical location to parametrically increasing aesthetic judgments regardless of condition in the medial orbitofrontal cortex (OFC) suggesting that it may be the site of a general response mechanism to subjective pleasurable and appetitive stimuli also evident in other neuroimaging studies (Aharon et al., 2001; Anderson et al., 2003; Blood et al., 1999, 2001; Kawabata et al., 2004; Kringelbach et al., 2003; O'Doherty et al., 2001, 2003b; Rolls et al., 2003; Small et al., 2001, 2003). This finding was further adopted in the second study.

In the second study we developed a specific experimental hypothesis to investigate a possible modulation in OFC (and other brain regions) as a function of aesthetic expertise. Previous research using a psychometric approach has demonstrated that level of expertise in art affects the evaluation of paintings (Hekkert & Wieringen, 1996). We developed the hypothesis that this difference may be modulated in OFC. In the first study we recruited subjects with no or little

training in the arts. In the second study we engaged subjects with an expert-knowledge in architecture and subjects with no training in architecture to accommodate our main question of interest; is there any dissociation, in neural terms, between experts and non-experts reflected by aesthetic judgments of architecture?

The third study further pursued a modulation of the cortical and subcortical regions involved in aesthetic judgment as established in the first and second study. Similar to the first study we recruited a homogeneous group of subjects; however we manipulated a semantic label accompanying the presentation of a homogeneous stimulus material consisting of original abstract paintings. Thus the aim of this study was to measure the effects of semantic information ('real art' vs. 'fake art') on the neural responses to aesthetic judgments. This experimental manipulation relates to a long standing question within the tradition of philosophical aesthetics. Arthur Danto (1964) has argued that no objects are inherently a work of art. What makes us experience objects as art is the institutional context they appear in. This is tantamount to saying, that objects must be cued as art to be experienced as art.

PART 2

HISTORICAL SURVEY

2.1 Cerebral functional specialisation

In the 19th century there was a great interest in how cognitive abilities might be localized in the brain. One view, set forth by the founder of phrenology Franz Joseph Gall (1758–1828) and Johann Christoph Spurzheim (1776–1832) (Gall & Spurzheim, 1809), was the idea that certain characteristics were ascribed to regions of the brain and thus the shape of the skull was indicative of the person's behaviour and general psychological profile. The phrenologists drew analogy to the muscular system where differential exercise would result in different forms. According to this logic it follows that a specific psychological characteristic is indicative of exercise to that part of the brain and therefore the part of the brain responsible will be enlarged. Despite the arbitrary nature of Gall and Spurzheim's phrenology their view was in principle the first account of functional localization. The concept of functional localization advocates that the brain is composed of many discrete neuroanatomical units, in which a special faculty is localized in each. This view was however in strong opposition to other views held at the time. Jean-Pierre-Marie Flourens (1794–1867) subscribed to a more "holistic" view of brain functioning. His view being that cognitive functions are global properties arising from the integrated activity of the entire brain (Flourens, 1842).

The first scientific evidence for functional localization came from Pierre Paul Broca (1824–1880), the first scientist to directly associate damage to a specific region of the cerebral cortex with a specific behavioural deficit. His patient, Leborgne, could understand language but had a deficit for using language in speaking and writing (Broca, 1861). Broca identified a lesion in the posterior regions of the frontal lobe, particular on the left side, and observed that the function of this area was for speech production. Broca's observation, that one region of cortex performs a specific role, was a key discovery related to functional localization. Further independent evidence emerged shortly after Broca's observation demonstrating functional localization. Fritsch (1838–1929) and Hitzig (1838–1907) in their studies of motor function observed that stimulation of the anterior parts of the frontal lobe in the dog resulted in

muscular contractions, where stimulation in the more posterior part did not do so (1870). Based on these early findings indicating a functional localization, Brodmann (1868–1918) advanced the search for functional localization further (1905). He divided the cortex up into 52 areas based on cytoarchitectonic differences. He used differences in cell layering and cell types to produce his maps. This technique is still widely accepted in mapping the cortex.

2.1.1 Functional specialisation of the visual cortex

Single-cell recording was pioneered by Edgar Adrian (1889–1977), and applied to the visual system of mammals by Stephen Kuffler (1913–1980), the mentor of David Hubel and Torsten Wiesel. Hubel and Wiesel recorded from single-cells in the visual cortex (area V1) both in the cat (Hubel & Wiesel, 1959; 1962) and later in the macaque monkey (Hubel & Wiesel, 1968; 1977). Hubel and Wiesel's basic findings were that different parts of the occipital cortex respond to the same stimulus at different levels of complexity. Specifically, in area V1 at the occipital pole of the cortex, they observed that "Each cell seems to have its own specific duties; it takes care of one restricted part of the retina, responds best to one particular shape of stimulus and to one particular orientation" (Hubel, 1963). On closer observation they found that cells with similar orientation preferences grouped together in vertical columns that seemed to form a hierarchy of increasing receptive field complexity. This hierarchy, according to Hubel and Wiesel, consisted of simple and hyper-complex (end-stopped) cells. The simple cells showed linearity within their receptive fields so that the firing rate of the neuron could be predicted from its input. Thus the more complex cells could then be built from the outputs of the simple cells. Upon summarizing these observations the subsequent proposal suggested that every aspect of the visual scene was processed in each area, but at a higher level of complexity.

Semir Zeki recorded from prestriate regions in the monkey (Zeki, 1973; 1974; 1977) and came to a different proposal (Zeki, 1978). Zeki observed variation in

responses relative to which area he was recording from. He observed that a region of cortex on the posterior bank of the superior temporal sulcus contained neurons that showed a strong preference for moving stimuli of certain directions over stationary stimuli. This area is today known as V5 (fig. 1). In contrast to this area, Zeki found a region of cortex in the prelunate sulcus containing neurons responding to colour, but not motion. This area was named V4 (fig 1), which in the human is located on the ventral occipital surface. From these observations Zeki proposed a theory of functional specialisation that was different from that of Hubel and Wiesel's in that the visual system was organised according to multiple, parallel, functional specialised systems (Zeki, 1978).

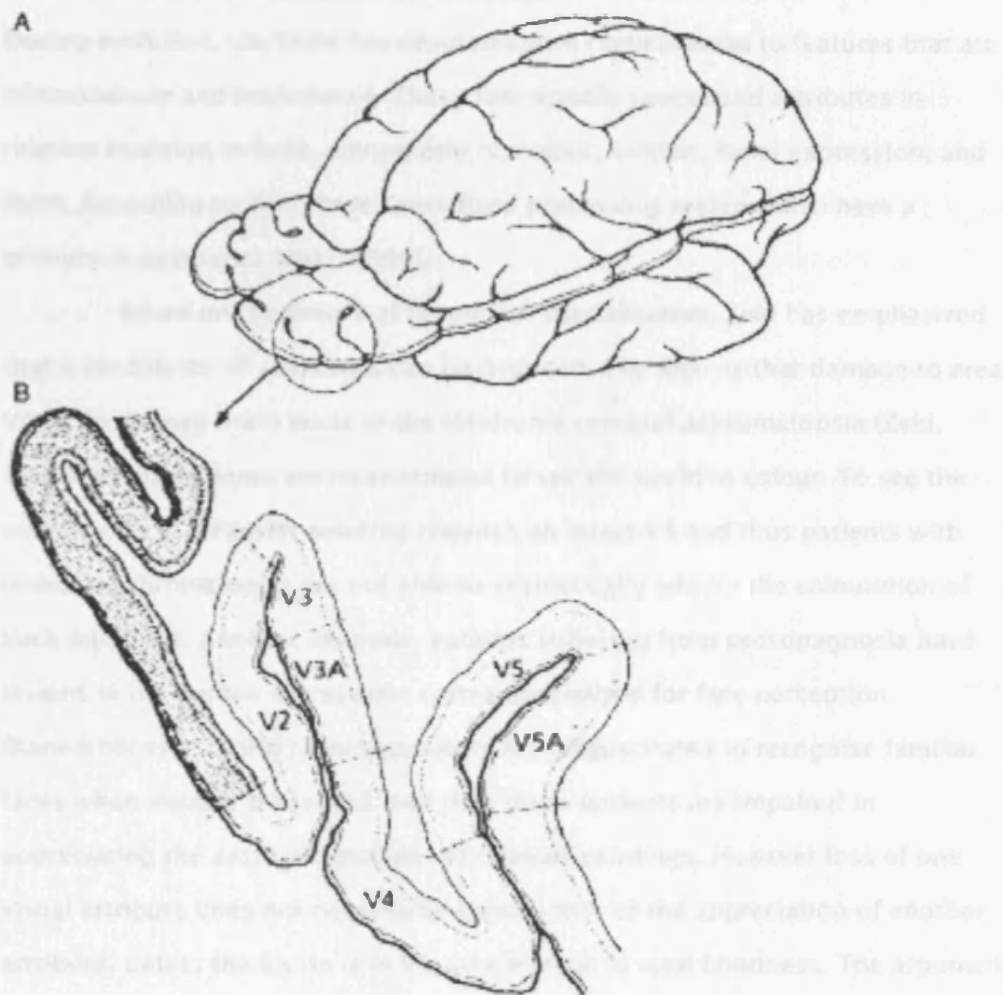


FIG. 1. Reconstruction of a horizontal section, taken through the brain of the macaque monkey at the level indicated, to show the positions of area V4 and area V5. Area V1 is shaded (Zeki, 1993).

The final confirmation of functional specialisation was made with the advent of neuroimaging techniques, first by Positron Emission Tomography (PET) and later functional Magnetic Resonance Imaging (fMRI), which would enable demonstrations of functional human activity at anatomical locations, such that functional specialisation today has been documented beyond doubt.

2.1.2 Functional specialisation of aesthetics

During evolution, the brain has devoted entire cortical areas to features that are of special use and importance. These functionally specialised attributes in relation to vision include, among others, colour, motion, facial expression, and form. According to Zeki these specialised processing systems also have a primacy in aesthetics (Zeki, 1999).

Based on the theory of functional specialisation, Zeki has emphasized that a modularity of aesthetics can be deduced. The logic is that damage to area V4 in the human brain leads to the syndrome cerebral achromatopsia (Zeki, 1990), where patients are incapacitated to see the world in colour. To see the colours of e.g. a Fauvist painting requires an intact V4 and thus patients with cerebral achromatopsia are not able to aesthetically admire the colouration of such paintings. Another example; patients suffering from prosopagnosia have lesions in the human extrastriate cortex specialised for face perception (Kanwisher et al., 1997). These patients are incapacitated to recognise familiar faces when visually presented, and thus these patients are impaired in appreciating the aesthetic qualities of portrait paintings. However loss of one visual attribute does not necessarily entail a loss of the appreciation of another attribute, unless the lesion is in V1, which leads to total blindness. The argument *is not* that the aesthetic effect of Fauvist or portrait paintings is solely due to activity in these functional specialised visual areas, but only that these areas are critical for recognition of these attributes.

These examples suggest that there is not only one visual aesthetic sense, but many separate categories of aesthetics, where each one is tied to activity of a functional specialised processing system (Zeki, 1997, 1999).

However there are also higher areas involved in aesthetics, namely in aesthetic appreciation and aesthetic judgments. Support for functional specificity of aesthetic judgments comes from the clinical literature of musical emotion. Patients with an impaired emotional response to music are generally accompanied by disordered musical perception (amusia). However dissociation between musical cognition and emotional processing has been suggested.

Evidence has been derived from patients with impaired recognition of music despite a preserved ability to make aesthetic judgments (Peretz et al., 1998). Furthermore, evidence that illustrates the reverse dissociation has also been reported, namely normal recognition of music, but inability to make emotional responses to music (Griffith et al., 2004). Together, these patient studies suggest dissociations between the perceptual and emotional components of music processing, indicating a functional specialisation for *aesthetic perception* and *aesthetic judgment*. Accumulating evidence from neuroimaging of normal individuals suggests that functionally and anatomically separable systems mediate music perception and emotion (Blood et al., 1999; for review, see Peretz et al., 2003).

2.2 History of neuroaesthetics

Semir Zeki has pioneered the discipline of neuroaesthetics and founded the *Institute of Neuroesthetics* (www.neuroesthetics.org). However the genealogy of this discipline can be traced back to insights from at least three disciplines. 1) Philosophical investigations of aesthetics. 2) Discussions among philosophers inspired Gustav Theodor Fechner to develop the psychophysical discipline of experimental aesthetics. 3) The *neuro*-scientific foundation of the field has been made possible to explore by the advent of the modern technique of fMRI. This technique will be explained in detail in part 3.

As the neurosciences reveal more about the functional organisation of the brain, neuroscientists have become interested in exploring the fundamentals of subjective processes underlying aesthetics (e.g. Kawabata & Zeki, 2004). But also other cross-disciplinary areas such as religion, morality, economics, and law are based upon the laws of the brain and therefore prone to neuroscientific exploration (Zeki, 2004a).

Obviously it is subjective processes that govern aesthetic judgments; however these processes have an objective and a common neural organisation that allows a stringent scientific exploration of aesthetics. Thus neuroaesthetics seek to understand aesthetic judgments in the organization and functioning of the brain (Zeki, 1999). In that sense neuroaesthetics is not a field that promises new insights to scholars of art-history and artists themselves, rather it is the opposite. Neuroscientists are in a position to take advantage of the artists, who show an instinctive knowledge of the brain. Studies by Zeki have demonstrated how different artistic currents, e.g. kinetic art and Fauvism, reveal important insights into the functioning of the brain (Zeki et al., 1994, 1998).

To appreciate neuroaesthetics as a scientific discipline it is essential to discuss the origin and the underlying history of the discipline. Such a discussion will be addressed in this section in an overview of the two areas from which neuroaesthetics is derived: the philosophical discourse of aesthetics (section 2.2.4) and the development of experimental aesthetics (section 2.2.5). This

section will furthermore review the early studies of neuroaesthetics (section 2.2.1 & 2.2.2). These studies are characterised by exploring specific artistic currents with implications for perception, e.g. kinetic art, which has provided information about motion perception, and Fauvism, with implications for colour vision. Indeed, an experiment in this thesis was inspired by the work of Rene Magritte in that his work has implications for the saliency of object perception. Thus, a discussion of the relevance of Magritte's work in a neuroaesthetic context will also be provided (section 2.2.3). These studies reflect a distinct category of neuroaesthetic studies that must be separated from the category of neuroaesthetics that explore the subjective processes involved in *judgments* of aesthetics. fMRI studies belonging to both these categories have been made to constitute this thesis.

2.2.1 Kinetic art

Kinetic artists have found that the purpose of kinetic art is not simply to simulate motion, but rather to subordinate other attributes, such as form and colour, to the dominant element of motion. Motion can be depicted in art independently of other attributes (Zeki, 1999). Indeed, it has been shown that when humans view an abstract coloured pattern, activity in area V4 increases, while activity in area V5 decreases (Zeki, 1999). Thus, kinetic artists have instinctively and unknowingly revealed a neurological fact about the brain. Zeki & Lamb (1994) distinguish three stages in the development of kinetic art. In the first, artists expressed the importance of physical movement in manifestos, but represented motion in static form. In the second stage, physical objects that are actually in motion were incorporated into art. The third stage was an attempt to separate motion from form and colour. Jean Tinguely designed a machine called *Homage to New York* (1960) that was explicitly built to self-destruct and thus liberate motion from form. Kinetic art never progressed further than this third stage until Zeki & Lamb (1994) studied the link between brain activity and perception of kinetic art. Zeki tested the hypothesis that, while viewing kinetic art, the brain

responds as if the stimulus is an actual object in motion (Zeki et al., 1993). While subjects viewed a static image that nevertheless gives a slight sense of movement (fig. 2), elevated activity was found in V5. When subjects viewed a visual stimulus which was actually in motion activity was seen in area V1 and V5. Thus, it seems that V5 creates illusory motion.

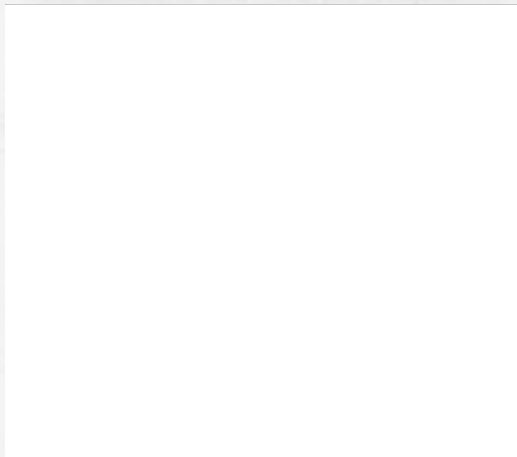


FIG. 2. Motion from static form in the figure called Enigma designed by Isia Leviant (Palais de la Découverte, Paris).

2.2.2 Fauvist art

The colourful artwork of another genre, Fauvism, is the optimal stimulus for area V4 of the visual cortex. Artwork that emphasizes a particular quality, such as motion or colour, seems to de-emphasize all other qualities to produce the stronger effect. This is similar to neurons in area V4 and V5 that are finely tuned to respond to particular stimuli.

Fauvism arose from the attempt to distinguish the subjective aspects of vision from the mere reproduction of nature. Fauvist painters found it interesting to depict the relationship between the object and the subject, the artist, his personality and his ability to represent emotions. For this reason, the Fauvists tried to liberate form and colour from the imitation of nature, adopting the solution of investing objects with unusual colours. A classic example is André

Derain's painting of *Charing Cross Bridge* (1906) (fig. 3). Such compositions, abnormal or un-natural in colour, also involve knowledge, to the extent that we learn to associate certain colours with certain objects. Zeki & Marini (1998) therefore further explored not only the brain areas that were activated when subjects view objects in their natural colours, but also when subjects enter a Fauvist world and view the same objects in abnormal colours. As expected, the naturally and abnormally coloured objects activated visual areas known to be involved in colour processing - V1 and V4. However, naturally coloured objects (e.g. red strawberries) also engaged the fusiform gyrus, hippocampus, and ventrolateral portion of the frontal cortex, which were related to object colour knowledge. Interestingly, abnormally coloured objects (e.g. purple strawberries) activated the dorsolateral area of the frontal cortex. The critical finding was that object colour knowledge was demonstrated by a differential activation pattern in specific brain regions.



FIG. 3. André Derain *Charing Cross Bridge*, London, 1906. National Gallery, Washington, DC.

2.2.3 Surrealism, the art of Rene Magritte

A study in this thesis was inspired by a third artistic genre with implications for perception, namely the Surrealists, more specifically the work of Rene Magritte (1898–1967). Indeed, an aim of this study was to cast a new light on this artistic current, from a cognitive and neuroscientific perspective. Magritte interpreted his art as a visual instrument “by which people might, via shock and surprise, become aware of the lie behind conventions and be able to find the way back to the mysterious essence of things” (Hammacher, 1986). Magritte developed a technique where he separated the pictorial objects from their conventional context and made the observer aware of the distance between the object and context (fig. 4). Thus, Magritte’s paintings sought to demonstrate the *relative* nature of the agreement between object and context. We thought it interesting to ask how this agreement is expressed in terms of brain activity. We expected that

the work of Magritte where a perceptual conflict is present would activate the parts of the frontal lobe, which are activated by the Fauvist stimulus material used by Zeki & Marini (1998). In both these genres of paintings there is a conflict to resolve, which has to do with the record of past experience and the conventional relationship between colour and object in the case of Fauvist paintings, and the relationship between object and context in the case of Surrealistic paintings.



FIG. 4. Rene Magritte *La Reconnaissance Infinie*, 1963 (Reconnaissance without end). Leslie and David Rogath Collection.

In the following I will give an overview of the neuroaesthetic history and origin in philosophical aesthetics and experimental aesthetics.

2.2.4 Philosophical aesthetics

The *Oxford English Dictionary* gives an instructive etymology of aesthetics: the word derives from a Greek root meaning to perceive by the senses. Traditionally aesthetics is defined as the science of beauty and the fine arts, but this definition was never unanimously accepted in the past. Its definition as a distinct discipline goes back to Alexander Gottlieb Baumgarten (1714–1767) who, in his book *Aesthetica*, in 1750 named aesthetics to be the science dealing with the lower faculties of experience, *gnoseologia inferior*, as he defined it, separating it from logic as *gnoseologia superior*, the science of the higher faculties of human experience. This reflects the division of the Aristotelian tradition between aisthesis (sensuous experience) and noesis (intellectual experience) as well as the neo-platonic devaluation of sensuous experience. It is interesting to note how Baumgarten in the first sentences of *Aesthetica* explicitly apologises to the scientific readers for dealing with such a suspicious subject like the fictions of human senses, for which he could state nothing else in his defence, but the reply that a philosopher should not reject any aspect of human life!

The evident dispute present in Baumgarten's *Aesthetica* was elaborated by an historian of aesthetics (Tatarkiewicz, 1980). In this work the polarity of objectivity and subjectivity of aesthetic experience is depicted as the most prominent one. It was a crucial matter of these disputes whether beauty was a property of the aesthetic object (i.e. a metaphysic quality expressed or represented by an aesthetic object) or a particular way of the subject to view the world and its objects. In other words: does beauty lie in the essence of things or in the eye of the beholder.

A closer look at the British Enlightenment also reveals evidence of this dispute. Aesthetics was understood in an inductive and not in a metaphysical way. The variety of aesthetic experience, of taste and its social character, became a main topic of aesthetic essays and treatises. As an example of the subjectivist view, David Hume wrote in his essay *Of the Standard of Taste*: "Beauty is no quality in things themselves: It exists merely in the mind which contemplates them; and each mind perceives a different beauty" (Hume 1757/(1964)). Hume

investigated the variety of taste as a fact of human life without distinguishing between good and bad or right and wrong judgments. The view held by Hume caused some dispute among the objectivist protagonists. How is it possible for beauty not to be intrinsic to the object itself, but dependant upon the observer? By Hume's statement we are steered to the discussion of how body and mind are connected. A dualistic position (that body and mind are two separate, independent entities) would argue that Hume's statement implies that aesthetics is a philosophical discipline whose truths are inaccessible to empirical methods. The question of the biological basis of aesthetics would, then, be impossible to explore. In opposition to this view, and in agreement with Hume's statement, it has been reasoned that the purpose of sensory perception is to gain knowledge about the world (Zeki, 1999). In order for knowledge to be gained from sensory information, perception must involve more than just reception of data; what is received must be recognised and organised; an active not a passive process.

German philosophers of that time derived aesthetic norms that represented the metaphysical value of beauty, while they described and illustrated what had to appear as beautiful to a cultivated mind. Books on aesthetics from that time often contained the word *catechism* in the title (Tatarkiewicz, 1980), and this normative tendency characterises the German literature about aesthetics for the most part. An exception, however, was Immanuel Kant (1724–1804) who like Baumgarten interpreted aesthetics as the science of aesthetic experience (aesthesis) according to the etymology sense of the term aesthetics. Kant in *The Critique of Judgment* (1790) opposed the definition of aesthetics as a 'science of beauty and the arts' and suggested to use the term partly in the transcendental sense, and partly in its psychological meaning.

2.2.5 Fechner and the foundation of experimental aesthetics

Based on these philosophical discourses, supported by the subjectivist view, steps towards an empirical foundation of aesthetics were taken by Gustav

Theodor Fechner (1801–1887), who was the co-founder of psychophysics. Fechner was the protagonist for a new empirical foundation of aesthetics, 'aesthetics from below', as he called it, which should support the traditional 'aesthetics from above' by a solid empirical and inductive approach. With his *Zur experimentellen Aesthetik*, a book published in 1871, and *Vorschule der Aesthetik*, a two-volume work from in 1876, Fechner was the first to emphasize an experimental approach to aesthetics. Fechner aimed at deducing aesthetic principles from the empirical comparison of the aesthetical effect of geometrical figures.

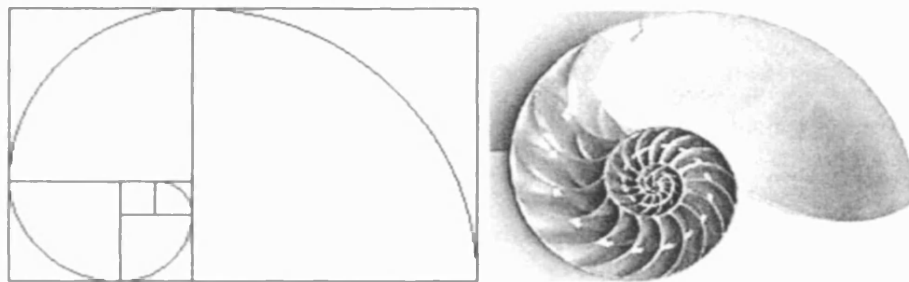


FIG. 5. Illustration of the golden proportion that according to the ancient Greeks is supposed to appear in nature, reflecting a naturalised aesthetic form.

Among the earliest accomplishments of experimental aesthetics put forward by Fechner was the *Principle of the Aesthetic Mean*. He exposed subjects to rectangles with sides of varying proportions and asked them which one they liked best. The rectangle closely approximating the Golden Section was selected by more subjects (see however, Weber 1931; Thompson 1946; for experiments that does not find the Golden Section to be most preferred). The Golden Section is a number, approximately 1.618, that was studied by ancient mathematicians due to its frequent appearance in geometry, and thus thought to reflect nature's balance between symmetry and asymmetry (fig. 5). Fechner concluded: "When an object of our contemplation undergoes random variation in size or shape, then, all other things being equal, the mean value seems to be preferred from the

aesthetic point of view or appears with the character of predominant pleasantness as the normal value in comparison with the others, which, according to their degree of deviation from the mean, can appear less pleasing or, if certain limits are exceeded, even displeasing" (1876). According to this statement the region of greatest pleasure is between the simple and the increasingly complex. It is interesting to note that since the Renaissance there have been attempts to specify the conditions for beauty and aesthetic pleasure. These have focused on the necessity of equilibrium between two factors. Descartes was among the first to do this in a statement that is strikingly close to that of Fechner: "(...) among the objects of every sense, the one that is most agreeable to the soul is not the one that is perceived by it either very easily or with great difficulty but the one that is not so easy to become acquainted with, that it leaves something to be desired in the passion with which the senses are accustomed to approach their objects or so difficult that it makes the senses suffer in striving to become acquainted with it" (Descartes, 1650. Quoted from Alanen, 2003).

Based on this century-long interest in the principles comprising aesthetic pleasure it is difficult to believe that Fechner's approach was so ill received at the time. The disputes following the writings of Fechner reflect the contradiction between arguments based on empirical evidence and arguments based on rational ideas. Eduard von Hartmann, one of the most engaged critics of Fechner's empirical foundation of aesthetics, argued that "(...) man takes more time over collecting empirical facts, the less he trusts the synthetic power of his speculative thinking" (1924). This statement demonstrates that the claim for 'aesthetics from below' hit a sensitive point of the self-consciousness of the academic aestheticians.

The novelty of Fechner's approach only becomes evident when considered in the light of the philosophical thinking of his time. Fechner in 1871 defined his work as 'aesthetics from below', which caused controversy in philosophical circles. It is this controversy that shows to what extent Fechner's academic approach was ahead of what was acceptable at the time. Before

discussing this dispute it is useful to look more closely at Fechner's approach in the way he described it especially in the preface of *Vorschule der Aesthetik*. In this book, Fechner characterises his scientific approach by giving up "the attempt to define the objective nature of beauty, and to develop a system of aesthetics starting from this point." Rather he wanted to use "the concept of beauty as an auxiliary term to find a brief designation, in the sense of linguistic usage, of things that unite in themselves conditions that lead to general liking." This turn away from the idealistic interpretation of the True, Good and Beautiful can be seen as a critique of a metaphysical concept of beauty. By trying to study the empirical conditions of liking, Fechner turns away from "conceptual developments on the basis of a definition of beauty." Thus, in his words, his approach takes a "direction opposite to the mainstream course." It is much more a bottom-up than a top-down approach, aiming at "clarification rather than intellectual elevation" (1876).

Fechner saw the aim of his empirical research in aesthetics as "explaining aesthetical facts through laws" that could only be proven in an empirical way. In Fechner's eyes, this did not exclude the normative definition of true beauty. However, these high level notions of beauty had to be constructed on the basis of precise knowledge of what was "likely to trigger a higher pleasure (...) directly from sensorial impressions and under which circumstances this was likely to occur with the probability of an intrinsic psychological law". Fechner was convinced that without such an empirical foundation "all our systems of philosophical aesthetics" would be nothing but "giants with feet of clay" (1876).

Another background, against which Fechner's "bottom-up aesthetics" stands out, is the formalistic aesthetics of his time. Johann Friedrich Herbart reduced the aesthetic act to the perception of form through "cold expert judgment" (Herbart, 1850) and dismissed any related emotions as a psychologically (side-)effect of aesthetics. Or Eduard Hanslick who in his book *Vom Musikalisch-Schönen* published in 1854, completely denounced the character of an "emotional", naive experience of music. In opposition to this, Fechner makes the emotional response to the aesthetic object the central focus

of his research. Fechner defined beauty as everything that “had the property of immediately causing liking – not only after reflection or through its consequences” (1871). Fechner establishes a direct link to the reality of experiencing beauty in everyday life, in a way that was taken for granted by the British philosophers of the Enlightenment for example, but not at all by German philosophy. From this it is evident that Fechner’s approach represents and stands in opposition to the aesthetic tradition in his academic environment. Shortly after Fechner’s publications, Eduard von Hartmann made a critical review in his *Die deutsche Ästhetik seit Kant* published in 1886. “So-called experimental aesthetics,” as von Hartmann puts it, “was therefore not yet aesthetics as such” but could “at the very best provide material for it” (1886). Fechner also received criticism from Benedetto Croce, one of the most important philosophical minds of his time. In the historical part of his *Estetica* (1902) he complains how many chapters Fechner needs to drag out the “chaos” of his theory, while being proud of behaving like a physicist (Croce, 1902).

Like von Hartmann, Croce dismissed the idea that Fechner’s experimental studies had any relevance to aesthetics whatsoever. Croce thought that only where Fechner writes about the concept of the beautiful in a speculative way, he would come up with aesthetic statements, so that one had to wonder why Fechner, although already having a theory about beauty and also about art, went to all the trouble of making principles and drawing up charts (1902). Despite the harsh critique that Fechner received for his ‘aesthetics from below’ his ideas were to be studied, particularly by empirical psychologists from the 1970s and onwards.

In the next section a review of the most important studies in empirical aesthetics will be provided.

2.2.6 Summary

This section has provided a brief genealogy of neuroaesthetics partly by a survey of philosophical discourses on aesthetics and partly by implicitly emphasizing

the similarities between experimental aesthetics founded by Fechner at the turn of the last century and the emerging field of neuroaesthetics. At its very basic, neuroaesthetics builds on the assumption first raised by the British Empiricists and thinkers such as Kant from the German Enlightenment, namely that perception (of the beautiful) does not reside in the object per se, but in the perceiver. This view is somewhat controversial in the traditional area of aesthetics and art-history in that scholars from this objectivist side ascribe to a more metaphysical way of aesthetical comprehension. Fechner received an objectivist-based critique when he established experimental aesthetics, which in many ways is strikingly similar to the claim that some art-historians use to reject neuroaesthetics (for an objectivist based critique of neuroaesthetics, see Ione, 2003). Of course neuroaesthetics use an approach similar to that of Fechner, but neuroaesthetics is rather to be seen as a sub-division of system-neuroscience that builds on the principle of functional specialisation. Thus, artistic currents such as kinetic art, Fauvism and Magritte's art can provide important information about the organisation and functioning of the brain. A separate category of neuroaesthetic studies is the higher faculties of aesthetics, such as aesthetic judgments and its interaction with emotional processes. This thesis attempts to resume these experimental questions regarding the nature of aesthetic judgments, i.e. the neural mechanisms involved in this act.

2.3 Empirical aesthetics

Having reviewed the philosophical underpinnings of neuroaesthetics, the following sections will review the scientific/experimental literature from several neuroscientific disciplines that are relevant in a neuroaesthetic framework. First I will describe a selection of studies from the discipline of empirical aesthetics. I will then turn to electrophysiological investigations of reward processing, identify cortical areas implicated in reward processing and relate these findings to the human. Then I will review functional imaging studies with relevance for neuroaesthetics. This is followed by a review of the neurological literature and indications of neuroanatomical lesions that lead to the disruption of visual aesthetic experience in the human.

In psychology, aesthetics has a long tradition as an empirical discipline, as established in the last section. In this section, I will review research from empirical aesthetics bearing on two factors that influence perceived beauty. First I will discuss objective features of stimuli, such as complexity, symmetry and exposure effects. Next, the role of the perceivers' affective responses in aesthetic paradigms will briefly be addressed.

2.3.1 Objective features of stimuli

Stimuli used for investigating individual differences in visual aesthetics ranges from simple visual stimuli such as polygonal figures (Berlyne, 1974; Birkhoff, 1933; Eysenck, 1941; Fechner, 1876) to complex stimuli such as works of art (e.g., Hekkert et al., 1996). However, approaches using abstract visual stimuli have been widely criticised. The main criticism is that these stimuli are not created for aesthetic appreciation. They do not have any artistic quality and are thus too far removed from what could be seen as aesthetic objects, such as a work of art (Berlyne, 1974). It seems that the essential point must be to define and quantify the stimuli used regardless of the nature of these. Given such stimuli it is then possible to relate their objective properties to subjective variables. We used works of art (experiment 3), photographs of natural scenes

and manipulated photographs containing incongruent objects–context relationships (experiment 1) and works of art depicting photographs of architecture and faces (experiment 2).

2.3.2 Stimuli complexity

The idea that the amount of information in a given stimulus is an important determinant of beauty has a long history in aesthetics and is related to the Gestalt tradition (e.g., Arnheim, 1974; Gombrich, 1984). Early on researchers focused on stimulus organization and proposed that perceived “goodness” (*Prägnanz*) of the stimuli depends on the relation between stimulus organization and psychological mechanisms (e.g., Koffka, 1935). Garner (1974) found that judgments of figural goodness were higher the less information subjects had to extract from the stimuli. The view taken by the Gestalt tradition has primarily focused on the amount of information represented in the stimuli, as their theory was consistent with the traditional assumption that beauty resides in the object (Attneave, 1954; Hochberg et al., 1953). However, philosophers and physiologists as established in the previous section have rejected this view.

The effect of visual complexity on preference has been investigated in a number of studies (Frith et al., 1974; Berlyne, 1970, 1974). Chris Frith and colleagues used an information–theoretical approach that allows objective measurement of pattern complexity, and found that a medium level of complexity was often preferred (measured by scales or relative preference). Berlyne (1974) analysed other psychophysical variables such as intensity, brightness, saturation, and size, and found similar results. Complexity is often related to preference by an inverted U-shaped function (Berlyne, 1974). With low levels of complexity, stimuli are not found interesting. As complexity increases, stimuli peak in terms of preference. However, further increases in complexity will eventually lead to a decrease in perceived preference. Indeed, as we saw in the previous section, Fechner also found these properties in his studies on the Golden Section.

2.3.3 Symmetry

Until Paul Ekman (1982) and others showed that the same facial movements express a wide variety of emotions cross-culturally, it was thought that facial expressions varied arbitrarily across cultures. Ekman made an important distinction between the expression of emotion and the cultural variation that may exist in the rules for displaying those emotions. Similarly, the general geometric features of a face that give rise to perception of beauty may be universal and shaped by natural selection (Langlois et al., 2000; Rhodes, 2006). Given the central role of faces in human social life and the importance of the face in physical attractiveness judgments of potential partners, it is not surprising that several studies have addressed the role of e.g. facial symmetry in attractiveness. Studies of symmetry in natural faces (e.g. Grammer et al., 1994) and digitally manipulated stimuli (e.g. Perrett et al., 1999; Rhodes et al., 1998) show that facial symmetry is positively correlated with attractiveness in both male and female faces. These observations are often explained by postulating an innate aesthetic sense in humans; however it is unclear whether it is sufficient to explain human aesthetics (Kirkpatrick et al., 1994).

2.3.4 Repeated exposure

A phenomenon that has been experimentally investigated known as the “mere exposure effect” (Zajonc, 1968) casts some doubt on the claim that the phylogeny of visual perception, e.g. symmetry as mentioned above, explains human preference behaviour. Paradigms based on mere exposure effects demonstrate that previous exposure to stimuli can increase subjects' subsequent preference for those stimuli (Zajonc, 1968, 1998). Mere exposure effects have been obtained with a variety of stimuli (faces, words, melodies) and a variety of measures (judgments of preference, behavioural choices), indicating the robustness of the phenomenon (for a meta-analysis see Bornstein, 1989; for mere exposure effects with works of art, see Leder, 2001). Interestingly, the effect has been demonstrated most strongly when stimuli are subliminally

presented such that subsequent recognition is implicit (Kunst-Wilson et al., 1980). It has been shown that previously seen stimuli differ from novel stimuli with regard to at least two parameters. First, familiar stimuli are processed faster than novel stimuli (e.g., Haber et al., 1965; Jacoby et al., 1981). Second, familiar stimuli elicit less attentional effects than novel stimuli (Desimone et al., 1995).

2.3.5 Subjective responses

Besides the properties of the stimulus material used in empirical aesthetics, another main issue in the field has revolved around the role of emotion in aesthetic experience. Some have considered that emotions are linked with aesthetic experience (Erdos et al., 2001), while others have considered such emotional responses to be essential for aesthetic experience (Neill, 2003). The reverse argument relies on the view that emotion is not sufficient for aesthetic experience (Kneller, 1998). Researchers have tried to separate these processes, e.g. Cupchik and Laszlo (1992) distinguished what they called a pleasure-based and a cognitive-based reception of art. The two aspects make the complexity of aesthetic experiences evident. For example, when interestingness is measured, then presumably the more cognitive aspects of the aesthetic judgments are considered, whereas beauty probably reflects more of the aesthetic emotions (including involvement). Aesthetic processing has often been measured using scales or responses for which the experimenter set the criterion. Most often the beholders were asked about how beautiful or liked an artwork was (Berlyne, 1974; Eysenck, 1968; Fechner, 1871; Leder, 2001), or which of two objects they preferred (Kunst-Wilson et al., 1980).

2.3.6 Experts and novices

Numerous studies have demonstrated profound differences in the aesthetic preferences between experts and non-experts. In general, people without art training prefer simple and symmetric visual elements, whereas people with art

training prefer complex and asymmetric visual elements (McWhinnie, 1966). Similarly, music novices prefer prototypical chord progressions, whereas experts do not show this preference (e.g., Smith et al., 1990). It seems likely that two different processes contribute to these differential preferences. First, training in the arts is likely to increase the meaning of complex structures in paintings, poems, or music. Second, experts are more likely than novices to consider aesthetic value, the ideas behind the work, and the norms of "good" and "bad" taste (Bourdieu, 1979; Gombrich, 1995). As a result, preferences expressed by experts reflect a disposition to "distance" themselves from the popular taste of non-expert viewers. It may be plausible to relate these differences between experts and non-experts to Berlyne's arousal-complexity scale mentioned above. Thus, experts prefer higher levels of complexity than non-experts.

It seems that in the 20th century, recognition and understanding of individual style have become essential for aesthetic experience. Thus, an aesthetic experience involves processing of stylistic information. Cupchik (1992) describes how style processing in abstract art depends on expertise, when he states, "Even highly abstract paintings can be constrained by rules, although the underlying principles are not immediately evident to those outside the artist's circle". It is questionable if the artist is aware of the underlying rules of his or her art, it might be that the artist is simply intuitively grasping the most effective rules (Zeki et al., 1994, 1997, 1998, 1999, 2002, 2004b). However it remains a fact that the art-critic often will be aware of the preferred technique and rules used by the artist to distinguish one style from another. Based on empirical studies on expertise, mentioned above, it might be that the level of expertise in art affects the evaluation of works of art. In this thesis we report an fMRI study that sought to investigate the extent to which the neural correlates of aesthetic judgment vary as a function of expertise in architecture (experiment 2).

2.3.7 Summary

In this section I have reviewed relevant aspects of the literature of empirical aesthetics. I have sought to categorize two main trends of research, namely studies with an emphasis on objective stimulus features, and studies using subjective evaluative judgment paradigms. Regarding the former; studies on symmetry and stimulus complexity suggests an innate sense of aesthetics in humans. However e.g. avant-garde art rely on the fact that new, and even initially despised shapes becomes liked by repeated exposure – known as the ‘mere exposure effect’. The conflicting view outlined above, between innate preferences versus mere exposure effects, leaves the role of experience and phylogeny in aesthetics unsettled.

On the subjective side of empirical aesthetics, it remains an unresolved issue whether emotion is essential for aesthetic judgments. Thus, by incorporating the distinction about the aesthetic-modus between experts and non-experts experiment 2 in this thesis has tried to locate a potential decoupling of emotional and cognitive processes involved in aesthetic judgment as a function of expertise.

2.4 Electrophysiology

In the following section I will, based on findings in the electrophysiological literature on reward processing, extract two essential factors that govern motivational aspects of reward, namely learning and hedonia. This is followed by a brief speculation about the neurophysiological correlate of cognitive abstract rewards, such as beauty.

2.4.1 The reward system of the brain

From an ecological point of view certain objects and events in the physical reality have special motivational significance to the brain, as they are essential for e.g. survival and reproduction. One class of these motivational resources is called rewards, which elicit and reinforce behaviour. One of the principal functions of rewards is to produce satisfaction (hedonia). This motivational value can be appetitive (rewarding) or aversive (punishing). Another key element in rewards, apart from its hedonic value, has been formalized by E.L. Thorndike in this statement: "Any act which in a given situation produces satisfaction becomes associated with that situation so that when the situation recurs the act is more likely than before to recur also" (Thorndike, 1911). Here Thorndike points out that the predictability of rewards works as a reinforcer. A popular theory in the neuroscience of associative learning is a continuation of Thorndike's basic idea, namely that the ability of events to enter into associations depends not only on their intrinsic hedonic properties, but also on how well the occurrence of those events is predicted.

The neuronal systems involved in processing rewards appear to be the dopamine system (for review, see Solokoff & Schwartz, 1995). Most researchers would agree that mesolimbic and mesostriatal dopamine systems are essential to reward, however they would seem to disagree about the exact significance of the psychological reward function mediated by dopamine. What information is encoded by dopamine release? An early and dominant view of dopamine function was that it acted as a hedonic signal (signalling pleasure) (Wise, 1988). This was

named the anhedonia hypothesis (or regarding normal dopamine function, the hedonia hypothesis), which suggest that the dopamine systems mediate the pleasure produced by food and other incentives such as sex and drugs. After the administration of dopamine antagonists, then, according to the anhedonia hypothesis “all of life’s pleasures (...) lose their ability to arouse the animal” (Wise, 1982). Although this view has been widely criticized due to evidence from pharmacological blockade (Berridge et al., 1998) in which animals continued to prefer (‘like’) rewards such as sucrose despite dopamine depletion (see section 2.6 for a discussion of dopamine and hedonia), and by Wise himself (Wise, 1994), the anhedonia hypothesis has become widely accepted; even the general public refer to dopamine as the ‘brain’s pleasure neurotransmitter’ (Berridge et al., 1998).

In recent years, however, alternatives to the anhedonia hypothesis have emerged to explain the role of the dopamine system in reward. Instead of acting as a hedonic signal, electrophysiological research has shown that dopamine is involved in reward-related learning or associative learning (Schultz et al., e.g. 1995). In the following these two aspects of reward, hedonia and learning, will be addressed.

2.4.2 Reward learning

Electrophysiological recordings primarily from the monkey have in recent years revealed anatomical locations and connections of neurons that are involved in reward-related learning such as the caudate nucleus, putamen, ventral striatum including the nucleus accumbens (Hikosaka et al., 1989; Apicella et al., 1991; Bowman et al., 1996), subthalamic nucleus (Matsumura et al., 1992), substantia nigra (Schultz 1986) and the amygdala (Nakamura et al., 1992).

Electrophysiological studies have made direct recordings of the firing rate of dopaminergic neurons in the monkey. During a reward-based learning paradigm a conditioned stimulus (CS) (a light) was made to serve as a signal for the delivery of food reward (Ljungberg et al., 1992). Two interesting observations

were reported: First, at the start of testing, neurons were found to be maximally sensitive to delivery of an unexpected reward (fig. 6A). The second finding was that responsiveness of the neurons changed with experience. With training neurons showed anticipatory firing in response to a cue signifying the delivery of reward (fig. 6C). Since the CS acquires rewarding properties through training, this observation indicates that dopaminergic neurons can be activated in an experience-dependent way, by prediction of the occurrence of rewards. This observation is in direct contradiction to the anhedonia hypothesis and suggest that dopamine neurons discharge in response to predictability of food rewards to a greater extent than when trained/experienced animals actually eats the food (i.e. before they presumably experience the pleasurable taste of food). This observation has subsequently been applied to theories on reinforcement learning (Schultz et al., 2000a). In the Rescorla-Wagner model (1972) the amount of learning that occurs on a conditioning trial is a function of the discrepancy between the intrinsic value of the reinforcer and the extent to which that value is expected on the basis of the cues present on that trial. Thus, dopamine neurons report primary rewards according to the difference between the occurrence and the prediction of reward, which can be termed as an error in the prediction of reward (Schultz et al., 1995, 1997, 2000b). Neural correlates of this prediction error have been observed in a variety of brain areas (reviewed in Schultz et al. 2000a), including the OFC in the human (O'Doherty et al. 2003a). Activity in this area has been reported when subjects perceive a mismatch between what they expect and what actually happen (Downar et al., 2001, 2002). Thus, novel tasks maximize learning (Shallice, 1988), and unless outcome violates expectancy, then learning parameters are not adjusted. These data finds resonance in an fMRI study (Fletcher et al., 2004), where the authors tested the above-mentioned formula in the human. A pattern of activity was observed in right dorsolateral PFC to the occurrence of unpredicted stimuli and it was concluded that this region is central for surprise-dependent learning in humans (Fletcher et al., 2004). Specifically, activity seemed to reflect the way in which subjects re-evaluated learned relationships or expectancies in response to unpredictability.

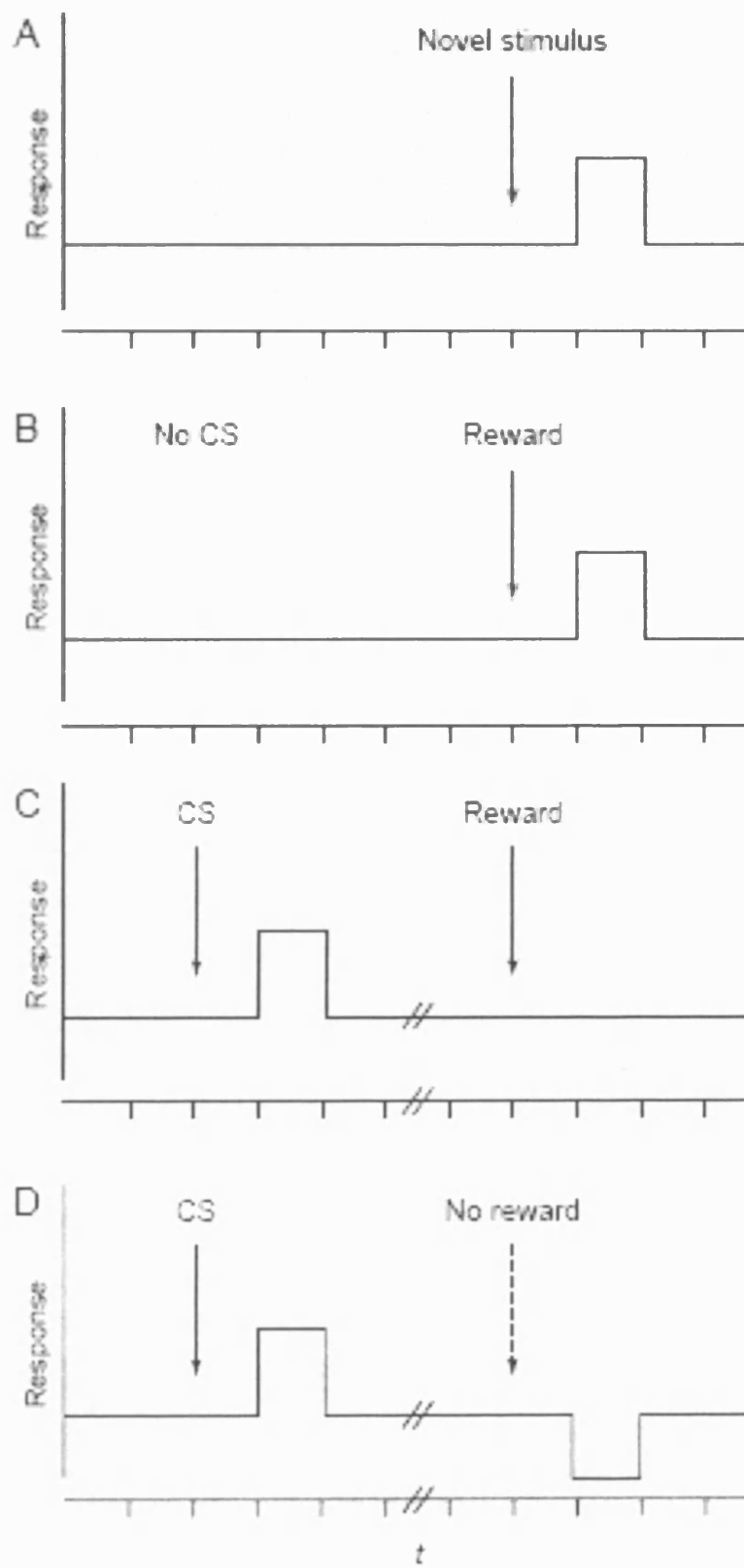


FIG. 6. Dopaminergic-cell responses to salient stimuli under the different experimental conditions described by Schultz et al. (1997). Each interval represents 100 ms. (A) The unexpected presentation of a novel stimulus elicits a burst of firing in a significant proportion of dopaminergic cells with a latency and duration of about 100ms. (B) A similar response is elicited by unexpected primary rewards. (C) When a conditioned stimulus (CS) reliably predicts a primary reward the burst of activity in dopaminergic cells transfer to the conditioned stimulus. (D) After conditioning, if an anticipated (predicted) reward is not delivered there is a short pause (~100 ms) in the baseline activity about 100 ms after the anticipated time of delivery.

2.4.3 Hedonia

Historically, the research on reward and hedonics initially started with intra-cranial self-stimulation (Olds et al., 1954). Olds et al. demonstrated that a rat with an electrode implanted in the medial forebrain bundle (MFB) would press a bar, which sends an electrical impulse to the electrode in the MFB to stimulate itself. Shocks from electrodes in the MFB produced response rates of more than 100 presses a minute, whereas stimulation in the adjacent areas caused a response of only about 10 presses a minute. This finding has led to the identification of brain reward systems that allow reinforcement of responses without homeostatic value. An interesting theory has been proposed that reward can be split into two components, namely incentive salience (wanting) and hedonics (liking), which have dissociable neural substrates (Berridge, 1996). Dopamine mediates the neural mechanisms of incentive motivation (wanting), but not the hedonic (liking) component of rewards (Berridge et al., 1998). In this sense hedonics is closely related to emotion. Emotional states are similar to hedonics in that emotional states and behaviour are elicited by rewards (and punishers) that normally are based on external stimuli and not associated with internal need states. This will be further elaborated in section 2.6.

Electrophysiological investigations have led to a hypothesis about the function of the OFC and its relation to emotion. However before elaborating on this hypothesis, associating the OFC with emotion, it will be informative with a short digression to the history of emotion.

2.4.4 Emotion and the orbitofrontal cortex

Emotion has interested scientists throughout centuries, but in recent years there has been a significant increase in research on emotion. The main problem with scientific investigations of emotion has been its definition. Ancient Greek and modern philosophers have discussed emotion extensively, but with the emphasis almost exclusively on its cognitive evaluation, and a definition of emotion useful for scientific inquiry did not seem to emerge. The field of emotion research began to make advances with Charles Darwin (1872), who examined the evolution of emotional responses and facial expressions. In the 1880s, William James and Carl Lange, independently of each other, proposed the idea that rather than emotional experience being a response to a stimulus, it is the perception of the physiological bodily changes which results in the emotional feelings (James, 1890; Lange, 1887). The James–Lange theory suggests that we do not run when danger arises because we are afraid, but that we become afraid because we run. This idea, however, did not address the question of what brain structures were involved in emotion. The James–Lange theory was applied to brain mapping by Antonio Damasio (1994) in the form of his somatic marker hypothesis, in which feedback from the peripheral nervous system controls the ‘decision’ about the correct behavioural response rather than the ‘emotional feelings’ as postulated in the James–Lange theory. An alternative to such bodily theories of emotions has been proposed by Edmund Rolls (1990, 1999). Rolls propose that the OFC is involved in emotion because it represents the reward and punishment value of primary (unlearned) reinforcing stimuli, and because it is involved in the re-learning and reversal of associations between previously neutral stimuli and primary reinforcing stimuli. Subsequent evaluation is represented in the OFC and influences, which behaviour is selected, which feelings are produced, and which autonomic responses are elicited. The intriguing aspect of this model is that it coincides both with the learning aspects of reward mentioned above and the hedonic states, which seems to be the two most fundamental reward relations to aesthetic judgments.

2.4.5 Summary and speculation on the neurophysiological basis of aesthetics

Could the aesthetic experience be described as a feeling of receiving a reward while looking at a work of art? A painting does not necessarily have a particular effect on our welfare and internal need state, (as a primary reward), but it could easily generate a very rewarding visual experience. Looking at something beautiful that has got the right proportions and chromatic arrangements is highly rewarding. In contrast to basic rewards, which relate to the reproduction of the species (i.e. incentive salience or wanting), the evolution of abstract, cognitive representations facilitates the use of a different class of rewards related to hedonics (i.e. liking). Concepts such as 'beauty' constitute this different class of rewards, which through evolution has become essential aspects of behaviour. It has been proposed that art can be regarded as a by-product of the brain's more essential aim, namely acquisition of knowledge, which has motivational value to the system (Zeki, 1999). The neuroaesthetic quest set forth in this thesis conforms to the question: Do such higher order cognitive rewards use the same neuronal reward mechanisms and structures as the more basic rewards? Do neurons that detect or expect basic rewards show similar activities with cognitive rewards?

Although cognitive rewards are difficult to investigate in an electrophysiological laboratory, it might be possible to adapt higher rewards such as interesting images to the study of brain function with neurophysiological methods. However, at present we are reliant on non-invasive imaging techniques to provide functional clues as to how cognitive rewards processed (for review on adapting cognitive rewards from electrophysiology to functional neuroimaging, see McClure, 2004).

2.5 Functional neuroimaging

Neuroimaging offers a way to investigate hedonic components in the human brain. One powerful approach is to use linear regression analyses to characterise brain areas at which the magnitude of the BOLD response is correlated with subjects' individual set of aesthetic ratings. This allows a unique window on the hedonic processes elevated by aesthetic salient stimuli. Recently, as will be reviewed in the following section, a string of neuroimaging experiments have investigated these hedonic processes for different types of reinforcers. Due to the relative novelty of the neuroaesthetic discipline, evident by the limited number of imaging studies in this field, it is useful to also address studies that are related to neuroaesthetics. Specifically, facial beauty has served as a favourite material for studying human hedonics.

2.5.1 Functional neuroimaging of facial perception

Facial beauty has received particular attention in the literature in that it seems to accommodate Darwin's original conjecture of an innate 'sense of the beautiful', which explains its importance in e.g. reproductive status (Etcoff, 1999). This view can be reflected in the diversity of imaging studies on the subject; facial beauty (Nakamura et al., 1998), attractiveness perceived in a smile (O'Doherty et al., 2003b), influences on gaze direction (Kampe et al., 2001), facial sadness and anger (Blair et al., 1999), fearful and happy facial expressions (Morris et al., 1996). Activation of medial OFC correlates with perception of attractive faces, and responses in this region seems to be further enhanced by a smiling facial expression (O'Doherty et al., 2003b). However given the obvious Darwinian association in facial beauty, is it possible that attractiveness co-varies with evolutionary important factors such as social aspects (Adolphs, 2003) or sexual arousing aspects (Hamann, 2004). A recent study has shown that sexual/rewarding and aesthetic aspects in facial perception yield differential activation patterns. Aharon and colleagues (2001) asked a group of heterosexual male subjects to rate the attractiveness of average and beautiful male and female

faces. Accordingly the beautiful faces were rated via key-press as more attractive, while the average faces were rated as less attractive, regardless of the sex of the face. A second group of male subjects were then asked to extend or shorten the length of time that a picture of a face remained on the screen, again based on attractiveness. It was hypothesized that male observers would gaze longer at those faces that were rewarding (i.e., the attractive female faces). Perhaps unsurprisingly, the results confirmed this hypothesis, with male observers choosing to gaze longer at the beautiful faces of the opposite sex relative to beautiful faces of the same sex. Even though beautiful male and female faces were rated to be equally attractive, the male observers only choose to gaze longer at the beautiful female faces, showing that only these faces were rewarding. In the subsequent fMRI experiment, the contrast of beautiful female faces > beautiful male faces (which would involve both reward and aesthetics) resulted in significant activity in both the right OFC and bilateral nucleus accumbens. At a lower threshold, activity was also found in ventral tegmentum and amygdala. Aharon and colleagues (2001) then investigated the effects of the aesthetics of facial beauty (i.e., beautiful male faces versus average male faces). As before, the ventral tegmentum was active; however, the amygdala revealed a negative signal response (deactivation). In addition to this, a bilateral deactivation was revealed in the nucleus accumbens. The pattern of activity revealed in the nucleus accumbens for aesthetic beauty is supported by studies of reward expectancy. For example, a decrease in the fMRI signal from baseline is revealed when an expected reward is not delivered (Knutson et al., 2001b). It would seem likely that the bilateral deactivation in the nucleus accumbens in Aharon and colleagues (2001) signalled an absence of reward expectancy toward the beautiful male faces. It is interesting to note that beautiful faces that are merely found aesthetic result in a negative signal change (deactivation) in the amygdala, again according to the findings of Aharon and colleagues (2001). This is surprising as the amygdala traditionally is thought to process threatening facial expressions (e.g. LeDoux, 1992). However, the notion that the amygdala is involved only in responding to negative and aversive stimuli is under question

(see review, Baxter & Murray, 2002). It has been found that the amygdala is recruited following the presentation of pleasurable stimuli (Anderson et al., 2003; Small et al., 2003). Furthermore, imaging studies have suggested that the amygdala is related to how arousing the stimuli are as opposed to valence of the stimuli (Anderson et al., 2003; Small et al., 2003). The amygdala might thus be related to stimuli intensity. Consistent with this is that pleasantness, but not intensity ratings has been correlated with activity in the medial orbitofrontal and anterior cingulate cortices for taste (De Araujo et al., 2003), odour (Rolls et al., 2003; Anderson et al., 2003), and chocolate (Small et al., 2001). In conclusion Aharon and colleagues (2001) revealed a noticeable dissociation of rewarding and merely aesthetic aspects of facial attractiveness.

2.5.2 Evidence of a dissociable reward processing

The areas involved in the reward system derived above have implications for distinct and dissociable aspects of reward processing with separate neural substrates. Electrophysiological experiments, as reviewed in the previous section, have shown reward-related activations in the ventral striatum (including nucleus accumbens) in both reward detection and reward prediction (Apicella et al 1991; Schultz et al 1992). The ventral striatum has connections to cortical and limbic regions; thus, processing in this region might reflect integration of reward-related information from areas such as the amygdala and OFC (Ongur et al., 2000).

Interesting findings based on behavioural methods in the rat have shown a selective role of dopamine in the nucleus accumbens in modulating 'wanting' aspects of reward, as mentioned in the previous section. 'Wanting' is related to motivational incentive value, but incentive wanting is not related to sensory pleasure. 'Liking' on the other hand codes for hedonic impact (Berridge et al., 1998). An empirical demonstration of the dissociation between 'liking' and 'wanting' of drugs (Lamb et al., 1991) showed that former opiate addicts would press a lever to get an injection of a low dose of morphine, even when the

subjective (hedonic) affects of the morphine were no different from those of a placebo and no state of physical dependence existed. The subjects would not continue lever pressing if it led to the injection of a placebo. Thus, low levels of morphine were apparently sufficient to sustain 'wanting' in spite of the fact that the substance produced no hedonic response.

2.5.3 Correlating subjective aesthetic judgments with BOLD

As shown above, imaging studies has been used to probe the relations between reward related areas of the brain and several basic types of sensory pleasure, such as food (Kringelbach et al., 2003), drugs (Breiter et al., 1997) and sex (Arnou et al., 2002). In recent years studies have increasingly tried to explore the neural basis of more abstract types of reward, such as love (Bartels et al., 2000), moral judgments (Singer et al., 2004) and aesthetic appreciation (Kawabata & Zeki, 2004; Blood et al., 2001; Vartanian et al., 2004).

Kawabata & Zeki (2004) asked subjects to view paintings belonging to four categories; portraits, still life, abstract and landscape that they considered beautiful compared to those that they found neutral or ugly. Besides showing category specific activations in fusiform face area for portraits and parahippocampal place area for landscape paintings, beauty ratings correlated significantly with voxels in the medial OFC. Similar findings have been reported in a PET study when subjects listen to music that elicits pleasurable experiences of "shivers down the spine" (Blood et al., 2001). In this study pleasantness of music correlated with right OFC. The role of medial OFC in reward is well established based on studies primarily in the macaque monkey, as shown in the electrophysiology section. However, in these two studies activation of the OFC differed. Kawabata & Zeki found left medial OFC and Blood and colleagues reported right OFC. Based on results from only these studies it is difficult to speculate about the reason for this trend, but it might be modality specific or due to stimuli presentation and subsequent evaluation differences. Kawabata & Zeki presented paintings with stimuli-durations of 2000ms, whereas another

fMRI study on visual aesthetics presented paintings for 6000ms (Vartanian et al., 2004). This study did not report activation in the OFC, but rather found that bilateral occipital gyri, cingulate sulcus, and bilateral fusiform gyri parametrically increased with increasing preference. These temporal differences in stimuli presentation might influence the way in which subjects evaluate paintings.

A differentiation in function between medial versus lateral areas of the human OFC was found in a study investigating visual discrimination reversal learning, which showed a clear dissociation between medial areas correlating with monetary gain and lateral areas correlating with monetary loss (O'Doherty et al., 2001). This result can be interpreted as evidence for a difference between medial OFC involved in decoding and monitoring the reward value, and lateral areas involved in re-evaluating current behaviour. Elliott and colleagues (2000) have also proposed a distinction between medial and lateral OFC. Elliott et al. propose that the OFC is activated when there is insufficient information available to determine the appropriate course of action and when this information is related to the reward value of stimuli and the response. Specifically, they propose that the lateral regions of the OFC are activated when the action selected requires the inhibition of previously rewarded responses, while they propose that the medial regions are concerned with monitoring reward value.

2.5.4 Visual areas involved in viewing emotional stimuli

Vartanian and colleagues (2004) emphasised the role of extrastriate cortex in processing paintings that vary in emotional value. As shown in a recent review (Phan et al., 2002), the majority of studies of visually induced emotional states have reported activation of the extrastriate occipital cortex. The visual stimuli that activated these areas were diverse (pleasant and aversive pictures). Reiman and colleagues (1997) have suggested that the visual associative cortex is involved in the evaluation procedure of complex visual stimuli with emotional relevance. It has also been proposed that the visual association areas are under control of top-down influences such that higher attention to emotional stimuli

may result in higher activity in visual association areas (Corbetta et al., 1993). An alternative interpretation would be that the differential response found in visual areas could be due to differences in the low-level visual features. However, this interpretation seems unlikely as in several studies matching visual stimuli for colour, luminance and complexity across emotional and neutral conditions does not cancel out the activation of visual association areas (Phan et al., 2002; but see Zeki et al., 1998).

2.5.5 Summary

In this section relevant neuroimaging studies have been reviewed that is linked to a neuroaesthetic framework. The overarching question present in this entire historical review is which neuronal reward mechanisms are involved and necessary for aesthetic judgments? Neuroaesthetic studies that have used explicit aesthetic judgment paradigms reflecting hedonics (Zeki et al., 2004; Blood et al., 1998), but not all (Vartanian et al., 2004) have shown the involvement of reward related areas, more specifically OFC.

Thus, from the results reported in this section the exact role that the primary and secondary (prefrontal regions) reward system plays in aesthetic judgments remains unsolved.

2.6 Neurology

Neurological conditions in human patients may provide anatomical indications to guide our search for brain mechanisms essential for aesthetic processing.

In an earlier section of this historical survey the neurological conditions of achromatopsia was briefly mentioned as supporting evidence for functional specialisation of aesthetic perception (section 2.1.2). In this section I will consider a neurological condition with implication for artistic production, namely frontotemporal dementia. Furthermore, lesions in the OFC will be considered, as this region frequently has been associated with emotional and reward processing. Finally, I will review a dopaminergic dysfunction known as anhedonia, which is associated with the incapacity to feel subjective pleasure.

2.6.1 Orbitofrontal lesions

Lesions in the OFC are of particular interest in a neuroaesthetic context due to this regions role in reward related behaviour. In humans, lesions in the OFC cause changes in emotion, personality, behaviour, and social conduct. Patients often show lack of affect and irresponsibility (Hornak et al., 2003; Rolls et al., 1994). A classic case of OFC damage is that of Phineas Gage, whose medial frontal lobes were penetrated by a metal rod (Harlow, 1848). Gage survived the accident but his personality and emotional processing was changed completely (although care should be taken because our information is sparse; Macmillan, 2000). Other cases of patients with OFC lesions was EVR who had a successful resection of an orbitofrontal meningioma involving a bilateral excision of the orbital and lower mesial cortices (Eslinger and Damasio, 1985). After the operation EVR performed well on IQ tests, but lost his job and wife as a consequence of his complete change in personality.

Analyses of the effects of lesions to the OFC show that they impair the patients in a variety of important ways related to emotion and decision-making. These changes can be measured by performance on neuropsychological tests

including gambling (Bechara et al., 1994) and decision-making (Rogers et al., 1999a), as described next.

Bechara and colleagues developed a gambling task to bring out cognitive deficits in patients with OFC lesions such as EVR. Subjects were asked to select cards from four decks of cards and maximise their winnings. During the task electro-dermal activity (Galvanic skin response, GSR) of the subject was measured as an index of somatic state activation. After each selection of a card, facsimile money was lost or won. Two of the four packs produced large payouts with larger penalties (and can thus be considered high-risk), while the other two packs produced small payouts but smaller penalties (low-risk). The most profitable strategy is therefore to consistently select cards from the two low-risk decks, which is the strategy adopted by normal control subjects. Patients with damage to the ventromedial part of the OFC, but not the dorsolateral prefrontal cortex, would persistently draw cards from the high-risk packs, and lack anticipatory GSRs while they considered risky choices. The task was designed to mimic aspects of real-life decision-making that patients with OFC lesions find difficult. Such decisions typically involve choices between actions associated with differing magnitudes of reward and punishment where the underlying contingencies relating actions to relevant outcomes remain hidden. Bechara and colleagues (1998) have since reported dissociation between subjects with different frontal lobe lesions. All subjects with OFC lesions were impaired on the gambling task, while only those with the most anterior placed lesions performed normal on working memory tasks. Other subjects with right dorsolateral lesions were impaired on working memory tasks but not on the gambling task. Bechara and colleagues (1999) went on to compare subjects with bilateral amygdala, but not OFC lesions, and subjects with OFC but not amygdala lesions, and found that all subjects were impaired in the gambling task and all failed to develop anticipatory GSRs. However, while subjects with OFC lesions still, in general, produced GSRs when receiving a monetary reward or punishment, the subjects with bilateral amygdala lesions failed to do so.

2.6.2 Frontotemporal dementia

Another important example of dysfunction of the OFC is frontotemporal dementia (FTD) which is a progressive neurodegenerative disorder attacking the anterior frontal lobes and producing major and pervasive behavioural changes in personality and social relationships resembling those produced by OFC lesions (Rahman et al., 1999). Patients appear either socially disinhibited, or apathetic and withdrawn. They tend to engage in ritualistic and stereotypical behaviour, and their planning skills are invariably impaired. The dementia is accompanied by gradual withdrawal from all social interactions. In contrast to patients with OFC lesions Miller et al. (1998) reported that a subset of patients with FTD developed artistic skills in the early stages of their illness. They were preoccupied with fine details of faces, objects, shapes and sounds, and these preoccupations were reflected in their art. Additionally, the art of patients with FTD share some common characteristics. In every case the art was visual, and was realistic rather than symbolic or abstract, and the images were highly detailed. Dorsolateral prefrontal areas responsible for working memory and episodic memory are spared in FTD enabling the ability to produce artwork of great detail. In contrast, semantic memory, which involve the left anterior temporal lobe are often impaired in FTD (Miller et al., 1998). The conditions under which patients with FTD develop artistic skills are not known (Miller et al., 1998). The obsessive-compulsive symptoms that sometimes accompany FTD may be necessary, but are probably not sufficient for the emergence of artistic preoccupations.

2.6.3 Anhedonia

Indications of a dysfunction of the dopaminergic reward system are found in severe depression, schizophrenia, and addictive disorders (Ebert, 1997; Heinz, 1999). It has been hypothesised that dysfunction of the dopaminergic reward system is associated with anhedonia, the inability to experience pleasure (Heinz, 1994; Loas, 1999).

Anhedonia has been considered as a fundamental symptom of patients suffering from dementia praecox and who were thought to be unable to feel “any real joy in life” (Alexander, 1986). Others have also described the striking indifference of schizophrenic patients but saw this characteristic as secondary to the disease state (Andreasson, 1982). Contrarily, anhedonia has also been considered as one of the main traits of the disease (Ansseau, 1988).

A classic attempt to account for reward and motivation was the anhedonia hypothesis of dopamine dysfunction (Wise, 1982). According to this hypothesis natural rewards, such as food or sex, and secondary rewards, such as narcotics, stimulate striatal dopaminergic neurotransmission. The resulting dopamine release may be experienced as subjectively pleasant and reinforce behaviour (food intake, drug consumption etc.) that induce dopaminergic stimulation (Koob et al., 1997; Robbins et al., 1996, Wise, 1988). Dysfunction of central dopamine receptors has been associated with a dysfunction of the reward system causing anhedonia. Patients with major depression and schizophrenia may withdraw from unrewarding social interactions, and among drug or alcohol addicts, an early relapse into drug taking may occur to stimulate dopamine release and to end the anhedonic mood state that follows detoxification (Koob et al., 1997).

Several primate studies have challenged this initial formulation of dopamine function, as mentioned in section 2.4. While dopamine neurons fire when a food reward suddenly arrives, the situation is different once the animal has learned that the food reward is preceded by a conditioned stimulus (e. g. a light cue). The dopaminergic neurons now fire exclusively when the reward-associated stimuli appear, but not when the animal later obtains the food reward (Schultz et al., 1993b). Based on these observations, Robinson and Berridge (1993) suggested that dopaminergic stimulation does not encode the pleasure of consuming a reward, but rather promotes the desire to obtain a reward (Robinson et al., 1993). Central dopaminergic stimulation would thus promote the ‘wanting’ but not the ‘liking’ of a reward. Consequently, central dopaminergic dysfunction may not present itself as anhedonia, but as a failure to

be motivated by reward indicating stimuli, which may manifest itself in the negative symptoms of affective disinterest or apathy (Andreasson, 1982). Thus, dopaminergic dysfunction would interfere with the motivation to seek pleasure, whereas the pleasure experienced once a rewarding situation is present would not be impaired.

'Wanting' and 'liking' a reward are usually closely linked. However, under pathological conditions, such as a dysfunction of central dopaminergic neurotransmission, these two mechanisms can be separately affected (Berridge et al., 1998), and a person may no longer be motivated to seek a reward while still able to enjoy a reward that is accidentally obtained. A decreased emotional reaction towards cues or stimuli that were previously associated with a rewarding situation and used to evoke desire may be the common psychopathological correlate of central dopaminergic dysfunction.

2.6.4 Summary

Lesions in the OFC quite severely impair subjective emotion, emotional behaviour, social behaviour, and, as a consequence, some types of decision-making. This makes the orbitofrontal cortex a region of primary interest in the elucidation of the functional neuroanatomy of human emotion.

It is frequently assumed that central dopaminergic neurotransmission reinforces behaviour because it is experienced as subjectively pleasant or hedonic, and that dopaminergic dysfunction is associated with anhedonia, the inability to experience pleasure. Present results support an alternative hypothesis, namely that dopaminergic neurotransmission mediates the desire for a reward rather than the pleasure of consuming or experiencing a reward. These observations may have important implications for the understanding of the role subjective aesthetic judgments in relation to central dopaminergic neurotransmission.

2.7 Conclusion

In this historical survey I have separated studies relevant in a neuroaesthetic context into four categories. This separation was done partially in an attempt to make an overview of studies from empirical aesthetic, electrophysiology, functional imaging (fMRI) and neurology to try to delineate the research area of neuroaesthetics. The result of such an approach is an extremely extensive survey of studies that only have one common theme in its relevance in a neuroaesthetic context. Thus one could not possibly address all the issues involved in one study. The review of the literature in this section has thus served as inspiration for the construction of the three fMRI experiments in this thesis. I have chosen to address the neural computation involved in aesthetic judgment from three different perspectives, i.e. in three fMRI studies. The problem encompasses how the brain may use different attributes to assess the reward value of salient stimuli in order to make aesthetic judgments.

PART 3

METHODS

3.1 Methodological overview

The experiments that constitute this thesis were performed using the non-invasive brain imaging technique known as functional Magnetic Resonance Imaging (fMRI). Thus the first subsection in this methodological section begins with a brief introduction to the basis of this technique (3.2). This is followed by a description of the Blood Oxygenation Level Dependent (BOLD) (3.2.1) and the haemodynamic response function (HRF) (3.2.2). A detailed outline of the various aspects of fMRI data processing (3.3), which includes a description of the pre-processing steps of the scanner output (3.3.1), and the subsequent Statistical Parametric Mapping (SPM) analyses that allows statistical inference to be employed using the general linear model (3.3.2) will be provided.

3.2 Magnetic resonance imaging

fMRI is a technique that allows a direct measure of changes in the cerebral haemodynamic response, which can be used as an indirect reference for neural activity. To explain the nature of this process it is necessary first to explain the basic principles behind the functional Magnetic Resonance Imaging (fMRI) technique.

The magnetic resonance signal arises from the protons (the nucleus of a hydrogen atom) present in brain tissue water. Thus the signal that MRI detects is due to the spin of the protons. The protons have a low-energy state when the subject enters the static magnetic field of the MRI scanner. In the presence of a strong magnetic field, the magnetic moment of these nuclei aligns along the axis of the magnetic field. By displacing their alignment through excitation with a radio-frequency pulse (RF), information about the nearby tissue is derived from the rate at which the hydrogen nuclei return to the low-energy state following the excitation, i.e. when the RF pulse is terminated the nuclei relax and the energy released in the local magnetic field during relaxation is measured by a receiver coil. The relaxation back to the original state can be described as changes in two dimensions, longitudinal (T1) and transverse relaxation (T2). The

transverse relaxation is of special significance for fMRI (Weishaupt et al., 2003). In an ideal homogeneous magnetic field, the transverse relaxation follows a constant and average signal decay. However, in physiological tissue the transverse relaxation is more rapid because of local field inhomogeneities. This relaxation is known as T_2^* relaxation. In the brain, the size of these inhomogeneities depends in particular upon the state of the local blood supply. This physiological state depends, in turn, on the neural activity. For this reason, measurement of the T_2^* parameter is an indirect measurement of neural activity (the BOLD effect is measured by a T_2^* contrast, see below). However it is not known how neuronal activity and haemodynamics are exactly related (Atwell et al., 2002).

3.2.1 The BOLD effect

The magnetic properties of haemoglobin have been known since Pauling & Coryell (1936) discovered that haemoglobin has different properties in the two different states; oxygenated and deoxygenated. When oxygenated, haemoglobin is slightly diamagnetic, but in the deoxygenated form it is paramagnetic. Magnetic flux is reduced in diamagnetic materials, i.e. the applied magnetic field is repelled. Paramagnetic materials, in contrast, have an increased magnetic flux, i.e. the applied magnetic field is attracted into the material. A change in haemoglobin oxygenation therefore leads to changes in the local distortions of a magnetic field applied to it, which forms the basis of magnetic resonance imaging (MRI).

Several decades after Pauling & Coryell's discovery it became possible to measure this property *in vivo* with MRI such that blood oxygenation was correlated with neuronal activity (Ogawa et al., 1990); the method was named the Blood Oxygenation Level Dependent (BOLD). The onset of neural activity leads to a series of physiological changes in the network of blood vessels, which are captured by the BOLD. With the realisation of echo planar imaging (EPI), suggested by Mansfield (1977) (for overview of EPI, see Schmitt et al., 1998),

which reduced the imaging time to a fraction of a second BOLD experiments has been widely used ever since (Turner et al., 1991).

3.2.2 Haemodynamic response function (HRF)

For the purposes of estimating the BOLD signal in an experimental paradigm, SPM makes use of a canonical haemodynamic response function (HRF). This model is an approximation of the complex interactions between neuronal activity, metabolic demand, blood flow, and oxygenation. As these effects have different time constants this results in an impulse response (IR) that is assumed to be the response of the system (as reflected by the MRI signal) to a brief, intense period of neural stimulation. Thus, the HRF can be thought of as the impulse response function to a single neuronal event. In the first second the HRF is dominated by the increased oxygen consumption rate which leads to a small negative peak, known as the 'initial dip' (Ernst & Hennig, 1994; Menon et al., 1995). This initial dip is followed by a positive peak that overcompensates for the decrease in oxygen by delivering an oversupply of oxygenated blood spanning the next 5–10s. Hereafter the HRF continues to a level below baseline where it stays for the next 20–25s before it returns to baseline (see fig. 7).

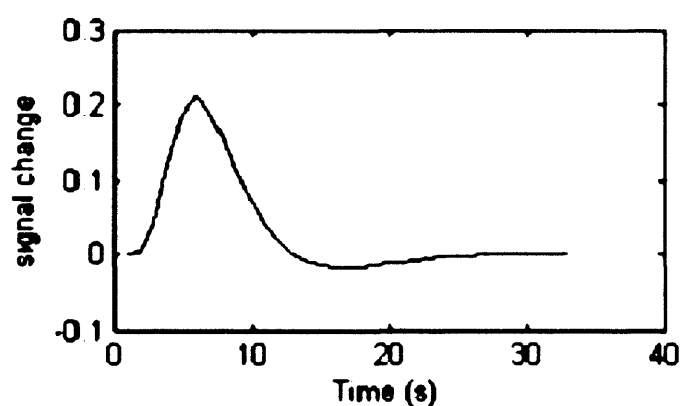


FIG. 7. Illustration of the SPM HRF. Shows a rise peaking around 6 sec, followed by an undershoot that persists for a considerable period.

Despite the stability of the signal provided by the haemodynamic response demonstrated above, evidence suggest that there is some variability in the exact form of the haemodynamic response across subjects, and possibly across different sensory and cognitive tasks (Glover, 1999; Martindale et al., 2003; but see Aguirre et al., 1998a). For example, Miezin et al. (2000) revealed differences in the timing and amplitude of the response from the primary visual cortex across subjects. Equally significant is evidence that the haemodynamic response varies across brain regions within subjects. Data from Buckner et al. (1998), for example, revealed the onset of the haemodynamic response in extrastriate cortex to be about 1000ms earlier than the response in prefrontal cortex during a word generation task, possibly due to variations in the vasculature of different regions (Lee et al., 1995). Thus in order to describe the shape of the expected response it is useful to employ a range of basis functions to account for the differences in the onset of the haemodynamic response across brain regions. Analysing using only one basis function may systematically ignore activity that does not conform to the profile of the HRF (Schacter et al., 1997). Due to this inhomogeneity or nonlinearity in the signal, the formulae for the HRF in SPM provide parameters that permit to approximate a range of the HRF by allowing multiple delays in the shape of the response (Friston et al., 1995b). These basis functions available in SPM provide some robustness in detecting experimentally relevant activity; they include temporal derivatives and dispersion derivatives (see fig. 8). In all studies in this thesis activity in prefrontal regions was a priori hypothesized and thus the HRF with time and dispersion derivatives were often employed to capture the latencies and duration in the shape of the response that are thought to occur in prefrontal regions (section 4.1 – 4.3 below describes which basis functions were employed in the specific experiments).

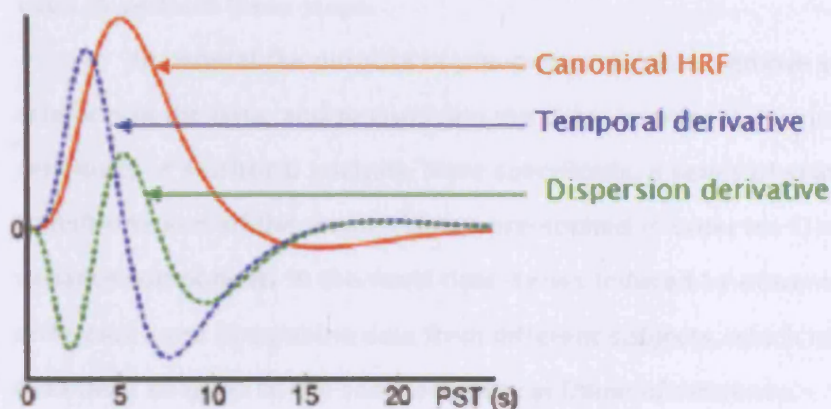


FIG. 8. The figure illustrates the shape of the canonical HRF and its temporal derivatives available in SPM. The canonical HRF is a 'typical' representation of the BOLD impulse response characterized by two gamma functions, one modelling the peak and one modelling the undershoot. To allow variation in the canonical form with respect to for example its peak delay and dispersion, parameters can be added as basis functions to better capture the signal. The temporal derivative can capture differences in the latency of the peak response. The dispersion derivative can capture the differences in the duration of the peak response.

Having described the basics of fMRI and the physiological characteristics that allow the use of this very powerful technique to capture neural activity, the next subsection will review the implementation of data analysis from the scanner output.

3.3 Data analysis

3.3.1 Pre-processing

Raw images from fMRI scanners require considerable pre-processing before changes in haemodynamic response produced by experimental conditions can be estimated, and allow statistical inference to be made. In this thesis the package Statistical Parametric Mapping (Wellcome Department of Imaging Neuroscience,

<http://www.fil.ion.ucl.ac.uk/spm>) implemented in MATLAB (Mathworks Inc.) was used to perform these steps.

In general the purpose of pre-processing is to remove various kinds of artefacts in the data, and to condition the data, in order to maximize the sensitivity of statistical analysis. More specifically, a series of spatial transformations of the scanner data were applied in order to: 1) reduce unwanted variance components in the voxel time-series induced by movement or shape differences and 2) combine data from different subjects, which require that the data must conform to the same anatomical frame of reference.

These transformations or pre-processing steps prior to statistical inference included spatial realignment, slice timing (temporal realignment), normalisation to a standard EPI template and spatial smoothing with an 8–12mm (full-width at half-maximum) 3-D Gaussian kernel. These steps will be described next.

The first five scans were discarded to allow for T1 equilibration effects (dummy-scan). The remaining functional images acquired from a single subject were realigned in order to correct for subject head motion. Excessive movement can lead to significant artefacts in the statistical analysis, typically affecting the anterior and posterior edges of the images. Thus, spatial realignment was implemented by estimating the six movement parameters of an affine “rigid-body” translation (x , y , z) and rotation (roll, yaw and pitch) that minimises the differences between each successive scan and a reference scan (usually the first post-dummy scan or the average of all scans in a time-series). The images were then realigned, by applying these translation and rotation parameters, using sinc interpolation to correct for head movement during acquisition. These transformation parameters were later used as measures of subjects’ head movements in the design matrix as regressors of no interest to further compensate for residual movement effects.

Slice timing correction ensures that the data from any given volume are sampled at the same time. However in real-time the different slices that comprise the complete brain volume were acquired sequentially, which varies

depending on the scanner acquisition time for one slice (1.5 Tesla, 90ms and 3 Tesla, 60ms). Thus the realigned data was exposed to slice timing that was temporally realigned to the middle slice to give the desired effect, i.e. that a single volume was captured at the same time.

To facilitate comparison between subjects and reporting of the data in a stereotactic reference space the data were then, following spatial and temporal realignment, spatially normalised. The normalisation technique involved determining a twelve-parameter transformation between the mean spatially realigned image of the scan time-series and the standard EPI template in SPM2. These parameters were then applied to all the functional images (using the EPI template provided in SPM2, which is similar to the average of 305 brains provided by the Montreal Neurological Institute, MNI), bringing them into a standard anatomical space. In this thesis the stereotactic space of MNI that conforms to the brain atlas of Talairach & Tournoux was used (Talairach & Tournoux, 1988). This code of practice has been established in SPM analyses in order to allow comparison to those voxels reported in previous studies, where this spatial co-ordinate system has been used.

After normalisation, spatial smoothing was applied using a Gaussian kernel. Smoothing refers to the process where the data points in a time-series are averaged. This is essential in fMRI analyses for two reasons. Firstly, smoothing the data will render the errors more normal in their distribution and ensure the validity of inferences based on parametric tests. Secondly, as Gaussian random field theory is employed to calculate the number of independent resolution elements (RESELS) for use in a Bonferroni-like correction for multiple comparisons, which assumes that the error terms are a reasonable representation of an underlying and smooth Gaussian field, it is required that smoothness be substantially greater than voxel size (Friston et al., 1991). Hence, data were spatially smoothed with a Gaussian kernel of 8mm FWHM (full width at half-maximum) in the second and third experiment, and 12mm FWHM in the first experiment to satisfy these statistical assumptions.

In addition to motion-related changes in signal intensity mentioned above, fMRI images contain other sources of noise. Modern scanners remain stable over extended scanning periods, so variability in the signal is mostly physiological in origin. At a typical repetition time (TR) of a few seconds, the dominant source of this noise is due to cardio-vascular and respiratory cycles. The frequency components that arise from cardiac and respiratory cycles will create an additional artefactual signal of relatively low frequency. These low frequency components can be modelled and removed with a low frequency cut off that effects a high pass filter cut-off of 128s, which was applied in all experiments.

The alternation of the experimental conditions creates a fundamental frequency for the task related activation that is sufficiently high to be clear of the low frequency region of the noise spectrum, without being so high as to be attenuated by the haemodynamic response.

During an experimental time-series, task performance results in successive haemodynamic responses to repeated neural activity that results in a cumulative effect, producing a certain level of activity. This allows inferences to be made about the variation in that level of activity; thus in the next subsection a description of the modelling aspects of fMRI data and the subsequent statistical inferences that can be employed will be presented.

3.3.2 Statistical analysis

Since the BOLD signal only represents a signal increase of about 5% with respect to the baseline, and with the standard deviation of the noise being of the same order, statistical analysis is needed in order to find the areas related to a performed task or sensory stimulation.

The application of statistical parametric mapping (SPM) appeals to *functional specialisation* as the underlying model of brain functions (see section 2.1). Activation maps are interpreted as regionally specific effects. In activation

studies regional activation is attributed to the sensory or cognitive processes that have been manipulated experimentally.

The approach used within SPM is a mass-univariate approach that calculates a statistic for every single voxel in the brain using the General Linear Model (GLM). User specified parameters are applied to create a design matrix of activation-effects either introduced by the experimenter (e.g. experimental conditions), related to the functional images themselves (e.g. global changes in cerebral blood flow) or unknown (e.g. drifts and shifts in the fMRI signal over time).

The GLM was introduced to fMRI by Friston et al. (1994; 1995a) who implemented it in SPM. SPM has for a decade been by far the most popular program for fMRI analysis. The current version of SPM (SPM2) was used in all work described in this thesis, I will therefore not comment on how the GLM is implemented in other packages.

A theoretical treatment of the GLM is useful to derive a simple equation that can be used for the analysis of any data set that can be formulated in terms of the GLM. Thus, in matrix formulation the GLM reads:

$$Y = X\beta + \epsilon \quad (3.1)$$

Here Y is the timecourse from a voxel in an fMRI dataset. The design matrix, X , contains the regressors of a multiple regression. The coefficient vector, β , contains the coefficients for each of the regressors. Finally ϵ is vector of independent and identically distributed (i.i.d.) errors.

A method of estimating the parameters (β) that 'best fit' the data is required, i.e. which finds the regression slope that minimizes the sum of distance between the observed data points and the fitted line. Thus, the regressors of interest are fitted to the GLM using a least-squares estimation method (Friston et al., 1995b), which for each voxel results in a set of parameter estimates reflecting the model fit to the data for each regressor, i.e. explaining a certain proportion of variance in the BOLD signal.

The particular differences of the parameters β that make up the effect are specified by a contrast vector, c , a vector of the same length as β , which specifies a linear combination of the parameters $c'\beta$. In SPM this is implemented using t-tests, i.e. a particular linear combination of the β 's of interest is generated under the null hypothesis that the regression slope, β , is 0 ($c'\beta > 0$). This makes it possible to assess the actual regression slope compared to the residual error at each voxel to generate a t-statistic. The t-statistics is then converted to probability maps using the Student's t-distribution.

Following equation 3.1 the experimental conditions are used to create a design matrix, which allow specific hypotheses or contrasts to be tested in order to make statistical inferences. Thus, each condition is fitted to every voxel comprising the whole brain volume, to estimate the size of the experimental effect in that voxel (a univariate approach). The design matrix contains one column for each hypothesised effect, and one row for each scan. More specifically, the onset and offset times for each different category of experimental condition are specified. The six realignment parameters obtained during the realignment pre-processing stage are also modelled as nuisance variables, and entered into the design matrix as regressors of no interest. The regressors of interest are then fitted to the GLM using a least-squares estimation approach as mentioned above. The design matrix is then convolved with one of the basis functions: 1) canonical HRF, 2) temporal derivative, and 3) dispersion derivative.

Appropriate contrasts between condition-specific effects are generated to make inferences about the experimental hypotheses. The SPM{t} is typically thresholded at $Z=3.09$ ($p<0.001$ uncorrected for multiple comparisons).

A general property of the statistical inference procedure is that the whole brain is examined simultaneously, giving rise to a significant problem of multiple comparisons. There are up to 150,000 voxels in a typical fMRI volume, although the smoothness of the data means the effective number of independent measurements within each volume is somewhat smaller. Small volume corrections (SVC) for Gaussian Field Theory are available within SPM software.

This allows the analysis (and estimation of p values) to be confined to small regions of interest. In this thesis we applied SVC with a sphere of 10 mm for regions in which we had a priori hypotheses. The alternative to this approach is to correct for every single voxel in the brain, which is probably rather too conservative (as it is usually possible to make a priori regional predictions or hypotheses about certain activations). The opposite of this is to report activations that are uncorrected for multiple statistical comparisons, which is probably rather too liberal. The general convention adopted in this thesis was therefore to assess significance based on uncorrected p values if the region of interest had been predicted a priori before the data was collected. For all other areas and activations not predicted a priori, we aimed at reporting corrected p values, unless otherwise stated.

3.3.3 Random effect and fixed effect analysis

Both within-subject and between-subject variability must be taken into account when making inferences about the population. There are two different statistical approaches that enable the effects measured in the subject to be generalised across different subjects, namely fixed effects (FFX) and random effects (RFX) analyses (Holmes et al., 1998; Friston et al., 1999a).

FFX analyses only take the within subject variability into consideration, not the between subject variability. As the between-subject variability is not taken into account, it is not possible to make formal inferences about the population from which the subjects were drawn, unless conjunction analyses are performed (Friston et al., 1999b). This also effectively means that the effect in one subject can potentially bias the average group effect, leading to the possibility of rejecting the null hypothesis even though the effect was not demonstrated in most subjects.

The alternative is a RFX where the subjects are drawn from a random population, which allows the sampling variability between subjects to be taken into account and so inferences can be made about the population from which the

subjects were drawn. This effectively removes the problem of individual subject bias inherent in fixed effects analyses. In all studies reported random effects analyses (RFX) were applied, where the data for each subject was entered into separate GLMs at the first level as described above. After model estimation, contrasts between conditions of interest were performed in such a way that the single '.con' image for each subject was raised to a second level GLM that produces a 'summary statistic' by means of a one-sample t-test, which establishes which voxels are significantly activated across all subjects.

3.3.4 Event-related and block designs

fMRI experimental paradigms can be either block designs or event-related designs. Block designs are characterized by a series of trials that in one condition is presented during an epoch of time. The signal acquired during blocked conditions is then compared to other blocks involving different task or stimulus conditions. Typically blocks will range in duration from 16sec to one minute, in a single fMRI run and multiple task blocks will be presented to allow the contrast of fMRI signals between task blocks. Blocked paradigms were the first approach to be employed in fMRI studies (Bandettini et al., 1992), and they were also the first to be targeted for the development of statistical analysis (Friston et al., 1994). Event-related designs on the other hand differ from blocked designs such that when the design is event-related each trial or event needs to be specified, whereas in a block design there will be no difference between modelling each event specifically or as a condition of one single long event. The advantage of detecting the modulation of haemodynamic activity to individual neural events in experimental designs is that it enables intermixing of different trial types, rather than blocking them. The counterbalancing procedure ensures that the average response to a trial type is not biased by a specific context or history of preceding trial types. Another advantage of event-related designs is that they allow experimental designs that cannot be easily blocked. As such, experiment 1 in this thesis could only be an event-related design whereby the 'oddball' (i.e.

abnormal conditions) deviates from the prevailing context and, therefore, cannot be blocked by definition (Strange et al., 2000). Experiment 2 was also an event-related design, whereas experiment 3 was presented in blocks.

PART 4

FMRI RESULTS & DISCUSSION

4.1 Experiment 1

4.1.1 Aims

Objects and their properties, such as contextual information, are related to each other by relationships that get incorporated in the brain through experience. The co-occurrence of objects and contexts in natural scenes provides a contextual expectancy when perceiving objects. The brain correlates of perceiving objects in normal contexts have been investigated in many imaging studies (Bar et. al. 2003, 2004; Aguirre et al., 1998b; Grill-Spector, 2003; Epstein et al., 1998; Maguire et al., 1998).

The aim of this study was to determine if the brain areas activated when perceiving objects in normal conditions are also recruited when perceiving objects in abnormal contextual settings.

To accommodate this aim we found it relevant to consult the paintings of the Surrealist painter Rene Magritte (1898–1967) who sought to give objects primacy by pursuing the relative relationship between the object and its context (fig. 9). Magritte ignored convention by placing objects in very unusual settings. Such compositions challenge observers' previous understanding and experience of the relationship between object and context by letting the observer question the intention of these abnormal compositions.

Another aim of this study was to investigate how object–context relationships would modulate aesthetic judgments. Thus, we incorporated an aesthetic judgment task in the design in order to perform interactions between stimulus conditions and aesthetic judgments. The aesthetic judgment task would furthermore allow us to test for effects of beauty specific to each stimulus condition and in addition, common areas involved in aesthetic judgment regardless of stimulus modality. To accomplish this we conducted a 1st order parametric regression analysis (Buchel et al., 1998) for the two stimulus types using the orthogonalized behavioural aesthetic judgments as regressors. To pursue these experimental aims we used manipulated photographs containing objects that were either consistent or inconsistent with their context.

4.1.2 Methods

4.1.2.1 Subjects

Fifteen subjects (four females, right-handed, mean age 24.4 years) participated in the study. Written informed consent from all subjects and ethical approval were obtained before the experiment. All had normal or corrected-to-normal vision, and none had a history of neurological or psychiatric disorders. Subjects were all fully educated undergraduate or graduate students. We excluded individuals with a formal education in art, or art history, as we wanted subjects' aesthetic ratings to be unaffected by prior knowledge.

4.1.2.2 Stimuli and task

Visual chromatic stimuli belonging to two categories, normal and abnormal, in total 120 stimuli, were selected from online sources. Abnormal versions were manipulated in Photoshop (version 7.0, Adobe, USA) by superimposing a photo of an object onto a different contextual background such that the object was in the foreground and appeared on a contextual background with which the object is not usually associated (i.e. abnormal conditions) (see fig. 9). Any image noticeable distorted (e.g. proportion and illumination) by this process was excluded from the stimulus pool. The normal versions consisted of photos with an object in the foreground on a contextual background with which the object is normally associated (i.e. normal conditions). All trials were presented in a pseudorandom order and counterbalanced across subjects. Each stimulus was presented once. A trial began with a fixation cross for 500ms. Stimuli were then presented for 3500ms followed by a question-duration of 2000ms (black screen), where subjects were instructed to press one of three buttons to indicate whether the image was appealing, neutral or not appealing. Total scanning-time per subject was 12 min. in one session. Before scanning, subjects were trained outside the scanner using demonstration stimuli which were not included in the scanning session. Stimuli were presented and responses collected using COGENT 2000 Graphics running in Matlab (Mathworks Inc.). The stimuli were back-

projected via a LCD projector onto a transparent screen positioned over the subjects' head and viewed through a tilted mirror fixed to the head coil.

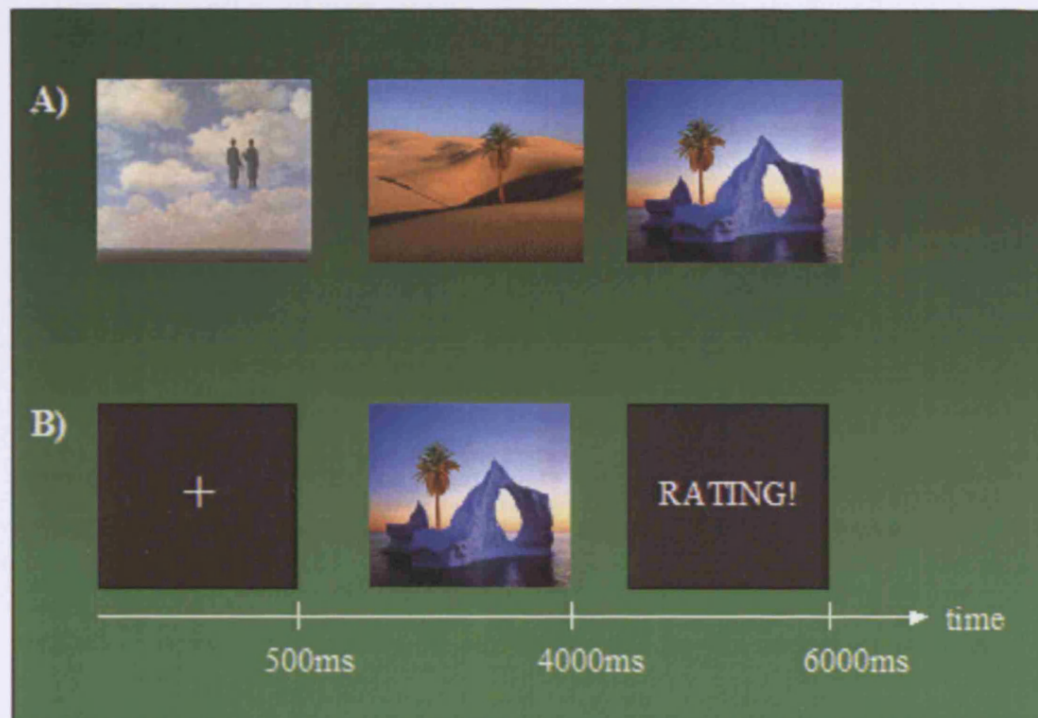


FIG. 9. (A) Painting by Rene Magritte, *Reconnaissance without end* (1963) that served as inspiration for the stimulus development. Two examples of stimuli used in the fMRI experiment are also presented; object in normal context and object in abnormal context. (B) Stimulus presentation paradigm. On- and offsets of the pseudo-randomised 6sec. stimulus epoch. Subjects were exposed to each stimulus in 3500ms followed by a rating period where subjects were required to make their aesthetic response via button press (2000ms).

4.1.2.3 Data acquisition

The functional imaging was conducted by using a 1.5T Siemens Vision fMRI scanner (Siemens, Erlangen, Germany) to acquire gradient T2* weighted echo planar images (EPI) to maximize the blood oxygen level-dependent (BOLD) contrast (TE, 40 ms; TR, 3.42 s). Each functional image was acquired in a descending sequence comprising 38 axial slices each 2.5mm thick, consisting of 64x64 voxels. This gave near whole-brain coverage, excluding the cerebellum.

Each session consisted of 220 volumes with the first 5 volumes being discarded to allow for T1 equilibration effects. After every functional scan, a T1 weighted structural sequence was acquired, using a phased array head coil to provide high-resolution anatomical detail. The structural image was co-registered to the EPI images so that functional data could be overlaid on a high-resolution anatomical image.

4.1.2.4 Data analysis

Pre-processing for this study included spatial realignment followed by slice-timing and normalization to the Montreal Neurological Institute (MNI) EPI template provided in SPM2. These data were then smoothed spatially with a Gaussian kernel of 12mm FWHM (full width at half-maximum), and filtered temporally with a band-pass filter with a low frequency cut-off period of 128 seconds. Following pre-processing, statistical analysis was carried out using a general linear model, in which each single event was modelled and convolved with SPM2's canonical haemodynamic response function (HRF). Data from all 15 subjects were applied in a random-effects (RFX) multiple regression analysis. We performed two analyses to investigate: 1) main effects of context and interactions between context and aesthetic judgment by applying linear contrasts of parameter estimates and 2) a parametric regression analysis using each participant's subjective aesthetic judgments as a parametric variable for normal and abnormal stimuli.

In the first analysis the following six boxcar regressors were convolved with the canonical HRF at the first level: abnormal-appeal, abnormal-neutral, abnormal-not appeal, normal-appeal, normal-neutral and normal-not appeal. Buttonpresstime and question-duration were modelled as regressors of no interest. Residual effects of head motion were corrected for by including the six estimated motion parameters for each subject as regressors of no interest. The resultant parameter estimates for each regressor (at each voxel) were compared

on the second level using t-tests to determine whether there were significant differences in activations between conditions.

In the subsequent 1st order parametric regression analysis, each subject's data was fitted with a parametric boxcar regressor, and convolved using HRF with temporal and dispersion derivatives, scaled according to each subjects' own set of aesthetic judgments (scores of 1–3), which modelled the onset and offset times of normal and abnormal stimuli epochs. For each contrast, the appropriate '.con' image for each subject was taken up to the second level where a random effects group analysis was carried out using a one sample t-test to identify voxels at which the magnitude of the BOLD response was parametrically modulated according to each subjects individual aesthetic judgments.

The statistical results given are based on a single-voxel *t* statistic corresponding to $p < 0.001$, uncorrected for multiple comparisons. In order to correct for multiple comparisons in interpreting these results we used small volume correction (SVC) with a sphere of 10mm radius for areas about which we had prior anatomical hypotheses. We used O'Doherty et al. (2001) for lateral OFC and Kawabata & Zeki (2004) for medial OFC.

4.1.3 Results

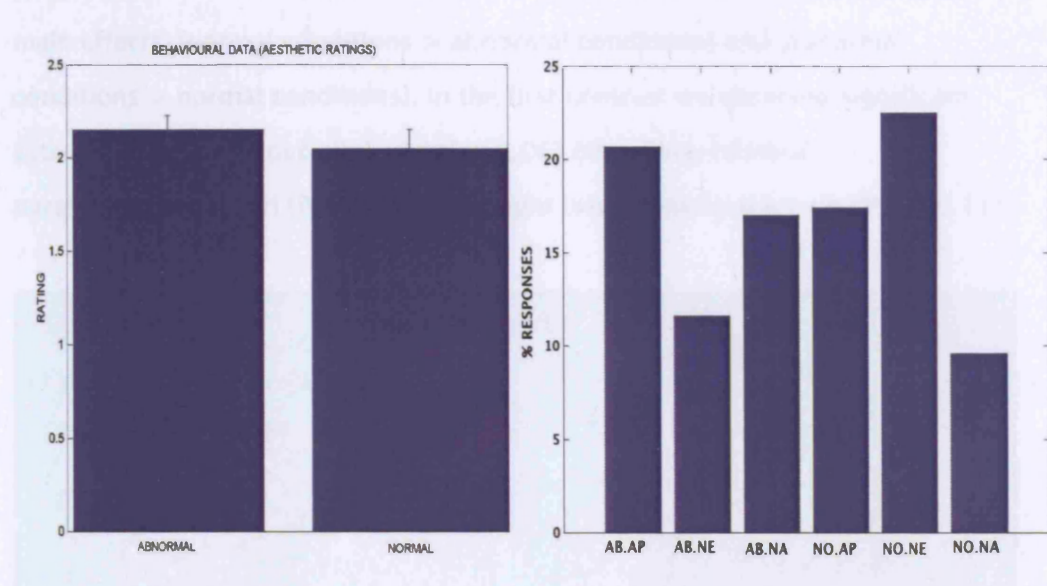
4.1.3.1 Behavioural results

Examination of the behavioural data collected during scanning showed that the abnormal stimuli was rated as being on average 2.15 (SEM=0.08) and normal conditions was on average rated as being 2.05 (SEM=0.1) on the aesthetic rating scale (1=not appeal; 2=neutral; 3=appeal). Statistical analysis revealed that there was no significant difference between aesthetic ratings for abnormal and normal conditions (paired $t = 0.88$; $df = 14$; $p < 0.39$) (fig. 10).

Subject-averaged reaction times (RT) for abnormal conditions was 764ms (SEM=13.6) and 818ms (SEM=44.4) for normal conditions. The two

conditions, abnormal and normal, did not produce significant differences in (RT) (paired $t = 1.37$; $df = 14$; $p < 0.3$) (fig. 10).

A)



B)

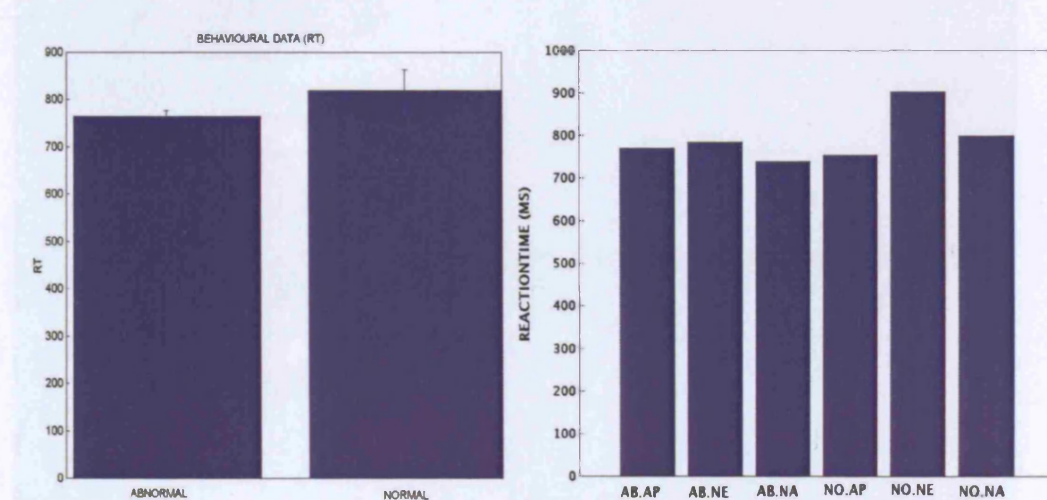


FIG. 10. Behavioural data ($n=15$) collected in the fMRI study. (A) *Left*: shows the aesthetic ratings for the two stimulus conditions, abnormal and normal. *Right*: shows the distribution of aesthetic responses for the two stimulus conditions, abnormal (AB) and normal (NO), across the three response types: appealing=AP; neutral=NE; not appealing=NA. (B) *Left*: shows the mean reaction times (RT) for each of the two stimulus conditions. *Right*: shows the distribution of RTs for the two stimulus conditions.

4.1.3.2 Neuroimaging results

The aim of this study was to compare brain activity caused by a visual object that is perceived in a normal contextual setting and the same object when it is perceived in an abnormal contextual setting. To achieve this we looked at two main effects; [normal conditions > abnormal conditions] and [abnormal conditions > normal conditions]. In the first contrast we observed significant activations in lateral occipital complex (LOC) bilaterally, bilateral parahippocampal gyri (PPA) and in the right inferior parietal lobule (IPL) (fig. 11).

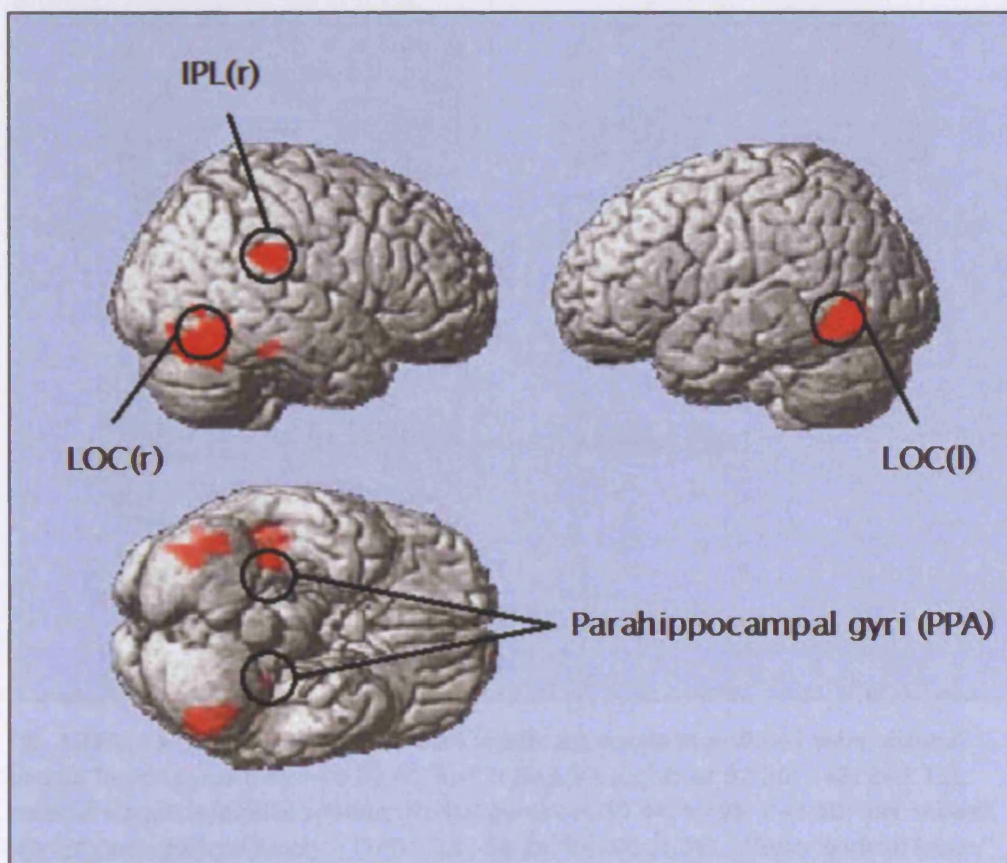


FIG. 11 Main effect [normal > abnormal] revealed significant activity ($p < 0.001$, uncorrected) in bilateral lateral occipital complex (LOC) (Left: $-46 -62 -10$; $k=266$; $Z=3.81$. Right: $40 -70 -24$; $k=173$; $Z=2.94$), bilateral parahippocampal gyrus (PPA) (Left: $-26 -36 -14$; $k=2$; $Z=2.64$. Right: $34 -32 -20$; $k=40$; $Z=2.94$), and right inferior parietal lobule (IPL) ($44 -30 26$; $k=223$; $Z=3.73$). Activations are surface rendered on the canonical SPM structural image.

In the converse main effect significant activations were seen in the middle frontal gyrus bilaterally and the anterior cingulate overlapping with medial superior frontal gyrus. Additionally we found activity in left temporo-parietal junction (TPJ), inferior parietal lobule (IPL) bilaterally, medial orbitofrontal cortex (OFC) and left posterior cingulate/retrosplenial cortex (fig. 12).

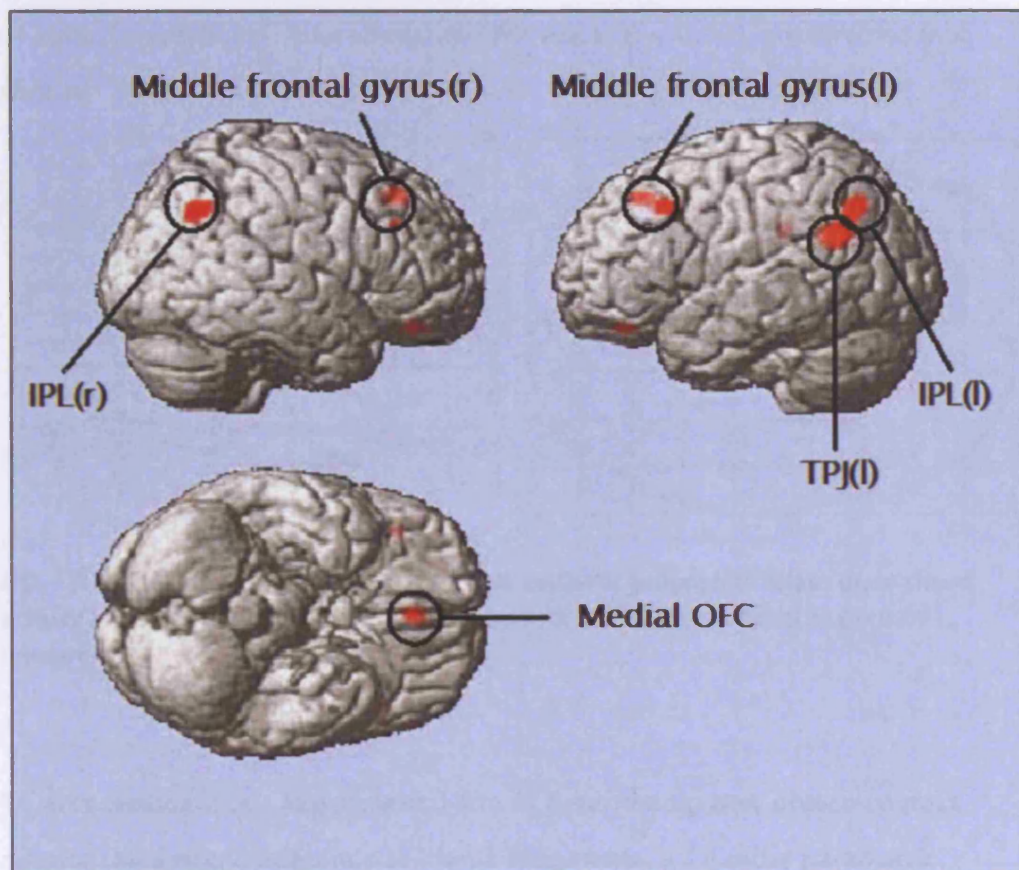


FIG. 12 Main effect [abnormal > normal] significant voxels at $p < 0.001$ were bilateral middle frontal gyrus (left: $-44\ 20\ 40$; $k=52$; $Z=3.50$. Right: $42\ 32\ 30$; $k=6$; $Z=3.19$), anterior cingulate/medial superior frontal gyrus ($-4\ 30\ 44$; $k=95$; $Z=3.50$) (not shown), left temporo-parietal junction (TPJ) ($-38\ -58\ 26$; $k=200$; $Z=4.39$), inferior parietal lobule bilateral (IPL) (Left: $-46\ -66\ 40$; $k=109$; $Z=3.50$. Right: $58\ -60\ 38$; $k=91$; $Z=3.65$), medial OFC ($0\ 40\ -20$; $k=18$; $Z=3.36$) and posterior cingulate/retrosplenial cortex ($-14\ -50\ 26$; $k=22$; $Z=3.30$) (not shown). Activations are surface rendered on the canonical SPM structural image.

A second aim was to investigate regions where abnormal and normal conditions are modulated by aesthetic judgments. To accommodate this aim we located

areas where the difference between appeal responses and not appeal responses was greater for abnormal compared to normal conditions. We performed the interaction [abnormal appeal > abnormal not appeal] > [normal appeal > normal not appeal]. The left temporal pole show distinct specificity to a modulation of aesthetic judgment of abnormal conditions vs. normal conditions (fig. 13). The converse interaction, where normal conditions were modulated by the presence of appeal, revealed no suprathreshold activity at $P < 0.001$ uncorrected (not shown).

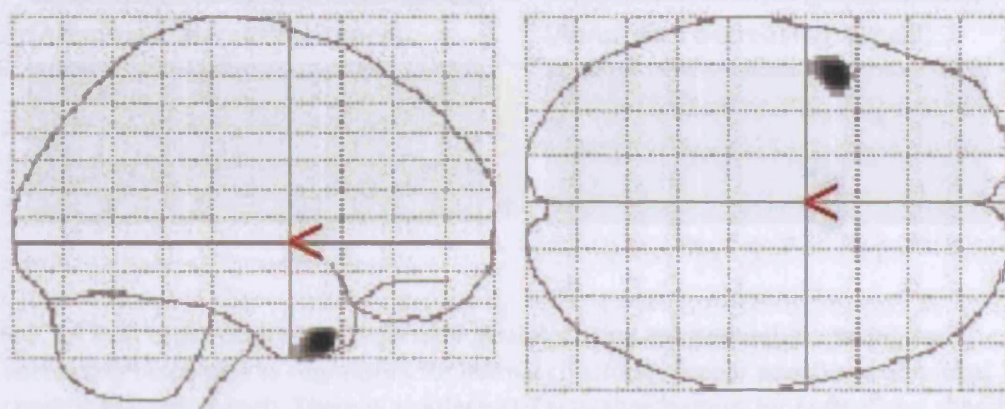


FIG. 13 Interaction between abnormality and aesthetic judgments. Glass brain shows activity in left temporal pole ($-46\ 10\ -36$; $k=115$; $Z=3.11$) significant at ($p<0.001$, uncorrected).

To accommodate our experimental aim of determining how object-context relationships would influence aesthetic judgments, a 1st order parametric regression analysis was used (Buchel et al., 1998). We looked for voxels at which the BOLD signal was correlated with increasing appeal ratings attributed to normal and abnormal conditions respectively. And furthermore we looked for voxels that correlated with decreasing appeal ratings for normal and abnormal conditions. We found activity in the right posterior cingulate for increasing appeal attributed to normal conditions. The opposite correlation, i.e. areas correlating with decreasing appeal ratings for normal stimuli, revealed activity in lateral OFC bilaterally (fig. 14).

Voxels correlated with increasing appeal for abnormal conditions in right frontomedian cortex/frontal pole and bilateral inferior frontal gyrus. Finally in the parametric regression for decreasing appeal in abnormal conditions the right lateral OFC was activated (fig. 14).

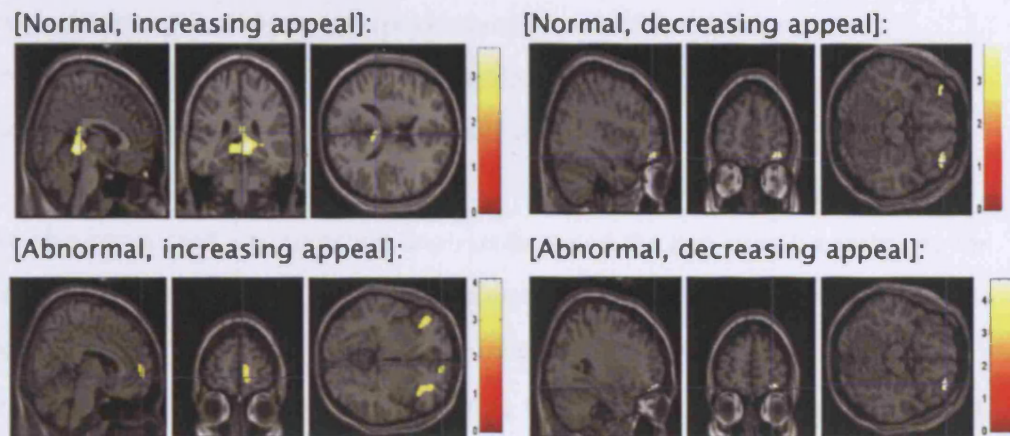


FIG. 14 First order parametric regression analysis using behavioural increasing and decreasing responses as regressors for normal conditions (upper panel) and abnormal conditions (lower panel). There is a differential activation pattern for normal and abnormal conditions: Normal increasing appeal ratings recruited right posterior cingulate (8 -38 6). Normal conditions with decreasing appeal activated right lateral OFC (36 50 -14) and left lateral OFC (-34 46 -14). Abnormal increasing preference resulted in activity in left inferior frontal gyrus (-38 34 4), right inferior frontal gyrus (38 28 -4) and right frontomedian cortex/frontal pole (12 54 10). Abnormal decreasing appeal responses resulted in right lateral orbitofrontal cortex (30 46 -20). All activation were found at $p < 0.001$, uncorrected. Activations are overlaid on sagittal, coronal and axial (transverse) sections of the canonical SPM structural image.

A conjunction analysis using the parametrically modulated linear increasing appeal responses for normal and abnormal conditions was performed to formally identify areas involved in aesthetic evaluation irrespective of whether the information was in normal context or abnormal context. No regions were found to reach significance ($p < 0.001^2$, uncorrected). However when we dropped the level of significance ($p < 0.005^2$, uncorrected) we found that medial OFC (2 50 -20; $k=15$; $z=2.79$) correlated with increasing preference ratings regardless of condition. This seems likely to reflect a general 'beauty' activation as previous

neuroimaging studies has found that medial OFC respond to beauty ratings in paintings (Kawabata & Zeki, 2004), facial beauty (Aharon et al., 2001, O'Doherty et al., 2003b) and pleasantness of sound (Blood et al., 1999). We therefore used small volume corrections (SVC) (Worsley et al., 1996) constraining our analysis to this a priori region (10mm sphere centered in our OFC activation, MNI-coordinates 2 50 -20). Using this approach, activity reaching corrected significance was observed ($p < 0.04$, small volume corrected) (fig. 15).

We also conducted a conjunction analysis between the two stimuli conditions for decreasing appeal ratings from the parametric analysis. This analysis revealed right lateral OFC activation ($p < 0.001^2$, uncorrected). The differential activations in OFC support previous reports indicating that abstract reward and punishment representations occur in the medial and lateral OFC respectively (O'Doherty et al., 2001). Thus we performed SVC (10mm sphere centered in right lateral OFC, coordinates 36 50 -14) which resulted in a corrected significance level ($p < 0.004$, FDR). (fig. 15).

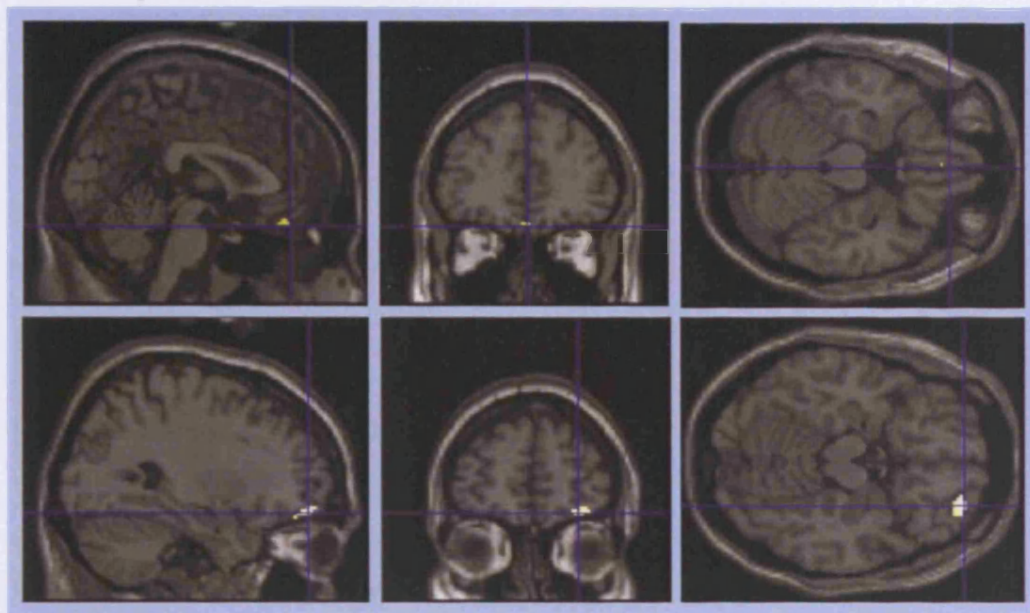


FIG. 15 Upper panel: A conjunction analysis ($p < 0.005^2$, uncorrected) was performed of the increasing appeal responses for normal and abnormal conditions from the parametric analysis. Voxels at which activity positively correlated with subjective aesthetic beauty ratings irrespective of condition were identified at the medial OFC (2 50 -20). After SVC this region reached a significant level ($p < 0.04$, FDR-corrected). The activation has been overlaid in sections of a normalised structural image. Lower panel: Activation in the right lateral OFC (36 50 -14; $k=88$; $Z=3.54$) in a conjunction between decreasing appeal ratings for normal and abnormal conditions from the parametric analysis. SVC in this region revealed a corrected significance level ($p < 0.004$, FDR).

Table 1

Brain region	MNI x y z	Voxels	Z score	p-value
<u>ABNORMAL > NORMAL</u>				
L. temporo-parietal junction (TPJ)				
	-38 -58 26	200	4.39	0.001
L. inferior parietal lobule/angular gyrus				
	-46 -66 40	109	3.50	0.001
R. inferior parietal lobule/angular gyrus				
	58 -60 38	91	3.65	0.001
L. middle frontal gyrus				
	-44 20 40	52	3.50	0.001
R. middle frontal gyrus				
	42 32 30	6	3.19	0.001
Medial superior frontal gyrus/anterior cingulate				
	-4 30 44	95	3.50	0.001
L. posterior cingulate/retrosplenial cortex				
	-6 -34 28	15	3.45	0.001
	-14 -50 26	22	3.30	0.001
Medial orbitofrontal cortex (OFC)				
	0 40 -20	18	3.36	0.001

NORMAL > ABNORMAL

L lateral occipital cortex (LOC)

46 -62 -10	266	3.81	0.004
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R. lateral occipital cortex (LOC)

40 -70 -24	173	2.94	0.001
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R inferior parietal lobule

44 -30 26	223	3.73	0.001
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R. parahippocampal gyrus(PPA)

34 -32 -20	40	2.94	0.001
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L. parahippocampal gyrus(PPA)

-26 -36 -14	2	2.64	0.004
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INTERACTION

[abnormal appeal > abnormal not appeal] > [normal appeal > normal not appeal]

L. temporal pole

-46 10 -36	115	3.11	0.001
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PARAMETRIC REGRESSION ANALYSIS:

NORMAL INCREASING PREFERENCE

R. posterior cingulate

8 -38 6	149	3.44	0.001
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NORMAL DECREASING PREFERENCE

R. lateral orbitofrontal cortex

36 50 -14	94	3.54	0.001
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L. lateral orbitofrontal cortex

-34 46 -14	48	3.38	0.001
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ABNORMAL INCREASING PREFERENCE

L. inferior frontal gyrus

-38 34 4	347	3.89	0.001
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R. inferior frontal gyrus

38 28 -4	324	3.25	0.001
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R. frontomedian cortex/frontal pole

12 54 10	124	3.00	0.001
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ABNORMAL DECREASING PREFERENCE

R. lateral orbitofrontal cortex

30 46 -20	150	4.35	0.001
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4.1.4 Discussion

In the results reported here we found a difference in neural activity when objects are perceived in normal context as opposed to objects perceived in abnormal context. More specifically these differences are reflected in engagement of frontal areas when a conflict between object and context occurs and engagement of LOC and parahippocampal areas when objects are presented in normal context. These results conformed to our prediction, based on Zeki & Marini (1998), and we will begin by discussing these. However, we also observed an interesting activation pattern in non-predicted areas of interest, which will also be discussed.

We found a medial-lateral trend in OFC that is likely to reflect a general response mechanism to evaluative judgments. Thus we confirm the involvement of the medial OFC in aesthetic evaluation as shown in a previous neuroaesthetic fMRI study from our lab (Kawabata & Zeki, 2004). In addition to these common areas activated by aesthetic evaluation, the results from the parametric analysis suggest a differential activation pattern that guide aesthetic evaluation of normal and abnormal conditions. Specifically normal conditions activate areas associated with semantic memory. Whereas an area involved in monitoring discrepancies between expectation and experience in memory encoding is activated in aesthetic evaluation of abnormal conditions.

The present study in relation to Zeki & Marini (1998)

For objects in abnormal contexts we observed activity in middle frontal gyrus bilaterally corresponding to BA 8, 9 and 46. Zeki & Marini reported similar activations. This region has been reported in previous neuroimaging studies, naming it the “oddball area” (Strange et al., 2000), as increased activity in this region was observed during deviation from sensory expectations whether it was perceptual, semantic, or emotional. In the Strange et al. experiment all stimuli were visually perceived words, which suggests that this area is active irrespective of whether it is a deviation from a purely sensory expectation or a cognitive

expectation. Furthermore it has been reported that elevated activity in this region might be sensitive to the relative rarity of the unexpected events (Casey et al., 2000). Thus, a “conflict”-trial is one that has been preceded by a number of trials of a different type (i.e. non-conflicting trials). Our results extend this interpretation in that “conflict” trials (i.e. abnormal conditions) occurred with the same frequency as non-conflicting trials (i.e. normal conditions). It seems possible that this region is a general response mechanism, whereby the brain abstracts stimulus configurations that are incompatible with their surroundings and to configurations that violate an expectancy based on preceding trials.

We observed an opposite activation pattern for normal conditions where no frontal regions were recruited, suggesting that each condition activates separate systems. We found bilateral activation in the LOC, in a region more lateral to the activation of Zeki & Marini. They interpreted the LOC as being concerned with the non-conflicting relationship between colour and object. Our study confirms and extends this finding in that the LOC also seems related to the non-conflicting relationship between object and context. We are puzzled that our activation of bilateral LOC was not activated when objects were in abnormal context in that LOC has been implicated in object recognition (Malach et al., 1995; Grill-Spector et al., 1999).

There were also differences between our study and that of Zeki & Marini. They reported activation of hippocampus bilaterally in the normal conditions. We did not monitor this region in our study. However we observed bilateral activation of parahippocampal gyri. Our activation overlaps with the area that constitutes the Parahippocampal Place Area (PPA) defined by Epstein and Kanwisher (1998) that respond selectively to houses and other environmental sceneries and landmarks. It is possible that due to the contextual stimulus material in the present study in contrast to the stimulus material used in the Zeki & Marini study we were unable to monitor the hippocampus, but rather found activity in the PPA. Our activation occupied a larger number of voxels on the right, which can be explained in accordance with previous studies showing that the right parahippocampal gyrus is most active during memory for landmarks

(Maguire et al., 1998; Mellet et al., 2000). A study relevant in this context presented evidence that the PPA and the retrosplenial cortex showed relatively higher activity to highly contextual objects (e.g. a blender) than to weak contextual objects (e.g. a cherry) (Bar et al., 2003). They found that PPA was sensitive to strong contextual objects presented with and without background information, with significant stronger activity for objects presented with background information. The retrosplenial cortex did not show this sensitivity, as the signal increase was equivalent regardless of the presence of background. The retrosplenial cortex is part of the posterior cingulate cortex, and in our study we found activation in this region for the opposite contrast, abnormal vs. normal. This area showed increasing signal changes in abnormal conditions and signal decrease in normal conditions. Our results thus confirm a bifurcation of contextual information processing, with the PPA more sensitive to normal visual appearance, and the retrosplenial cortex (posterior cingulate) processing information independent of specific stimulus properties. This interpretation is in accordance with the general role of the region in analysis of spatial information (Maguire et al., 1999; Burgess et al., 2001; Bar et al., 2003) and thus links the retrosplenial cortex to the retrieval of semantic information in frontal areas in abnormal conditions. A separate activation pattern is evident in non-conflicting conditions where objects are grouped according to physical appearance in LOC, and grouped according to contextual relations in the PPA.

Involvement of theory of mind in processing abnormal stimulus configurations

We were quite surprised to find an interesting activation pattern for the contrast [abnormal > normal] that included areas involved in *theory of mind* tasks (ToM). ToM refers to the ability to attribute independent mental states to the self and others in order to understand and predict behaviour (Frith & Frith, 2003). Activation of the TPJ with coordinates within the region of our activation has been consistently reported during ToM tasks (Frith & Frith, 1999, for a review; Gallagher et al., 2000). In Gallagher and colleagues 2000 one condition involved

a cartoon-drawing, where the task was considered to require ToM for its interpretation, i.e. attribution of either false belief or ignorance to the characters in the picture was vital for comprehension. Our results may suggest that TPJ is sensitive to stimuli, which signal intentions that are not immediately comprehensible. In support of this, the activation found in the OFC may reflect a violation of expectations. Activity in this area has been reported when subjects perceive a mismatch between what they expect and what actually happen (Downar et al., 2001, 2002). Further evidence for ToM involvement in our study is centred in the anterior cingulate region overlapping with the medial superior frontal gyrus. This region has been consistently associated with ToM (Frith, 2001; Gallagher & Frith, 2003; Gallagher et al., 2000; Fletcher et al., 1995). Viewing objects in abnormal context would presumably require subjects to attribute intentions to the stimuli in order to comprehend it, and thus it might be plausible that ToM was involved in this task.

The interaction effect in left temporal pole also seems to fit a ToM interpretation. fMRI studies implicate the temporal poles in personal semantic knowledge and episodic memory retrieval in visual and auditory domains. The temporal poles are activated in emotional memory retrieval (Dolan et al., 2000) and autobiographical memory retrieval (Fink et al., 1996) and during recollection of familiar faces and scenes (Nakamura et al., 2000). The temporal poles specificity to personal semantic and episodic memories has in ToM studies been interpreted as the importance of semantic memory for anticipating the likely goals of people and situations in order to avoid social norm violations (Berthoz et al., 2002). It is interesting to note that the interaction effect in left temporal pole were an effect in which aesthetic judgments modulated the two stimulus conditions, i.e. activity showed greater responses to abnormal appealing conditions relative to abnormal not appealing conditions compared with normal conditions. This provides evidence in favour of our suggestion that this additional activity may reflect subject's attempt to determine the intension or interpretation of abnormal stimuli that are found rewarding (i.e. appealing). Thus, the left temporal pole may participate in the detection of incongruity,

suggesting a role in the juxtaposition of mental states and the maintenance of semantic knowledge during aesthetic judgment. Clinical evidence supports our finding in that patients with semantic dementia show atrophy in the anterior temporal lobes, especially on the left (Chan et al., 2001). Interestingly, a prediction can be generated from these results. It can be predicted that patients with lesions to the anterior temporal regions should show impairment on ToM tasks (Gallagher & Frith, 2003).

We are puzzled about this trend in our results in that our study did not include involvement of the mental state of the self and others. However, it has been argued that ToM is based on autobiographical experiences (Vogeley et al., 1999) and thus a self-referential process. It may be plausible to expand ToM to also be involved in the self-initiation of a cognitive process in the context of perceptual conflict that require the active utilization of the subject's previous knowledge in order to interpret and comprehend the image. Indeed, Magritte has emphasized that his paintings were a visual instrument "by which people might, via shock and surprise, become aware of the lie behind conventions and be able to find the way back to the mysterious essence of things" (Hammacher, 1986). By "the mysterious essence of things" Magritte meant a relationship between objects and their contexts that were not obvious to the observer, but required an interpretation where the intentions of the paintings were hidden.

We have suggested that the increased BOLD responses in the TPJ reflect engagement of ToM. However, might activation of TPJ reflect elevated attentional demands for objects in abnormal context rather than ToM engagement? We suggest an argument against this possibility. The activation of TPJ was distinct from the activation of the angular gyrus in the posterior part of the IPL. The latter region has been consistently related to spatial attention (Vandenberghe et al., 2001) and is frequently activated in "oddball" tasks (Strange et al., 2000). However, the TPJ has to our knowledge not been reported in "oddball" experiments, which suggest that the TPJ is activated independent of the abnormal nature of the stimuli but rather reflects the intentions ascribed to the abnormal stimuli. Thus, it seems possible that the TPJ activation is best

explained in relation to ToM. The abnormal stimuli were not equated for difficulty in comprehension, which may have been reflected in a differential level of involvement in this region. Thus we are unable to confirm this possibility.

Involvement of medial and lateral OFC in aesthetic judgments

In the fMRI study of Kawabata & Zeki (2004), subjects viewed portrait, landscape, still life, and abstract paintings that they considered to be beautiful, compared to those that they considered neutral or ugly. Comparison of beauty vs. ugly conditions yielded significant voxels in the medial OFC. The involvement of the medial OFC to rewarding stimulus across a range of experiments (Aharon et al., 2001; Blood et al., 2001; Francis et al., 1999; O'Doherty et al., 2003b; Rolls, 2000; Small et al., 2001) in which the stimulus material varied considerably, can be explained by the unifying theme of making responses based on instinct or the feeling of "rightness" (Elliott, 2000), as opposed to rational analysis. The same reasoning could be applied to the activation we observed in the conjunction analysis of increasing preference responses that revealed common activation of medial OFC regardless of stimulus condition. Furthermore, we found that right lateral OFC correlated with decreasing preference ratings in the parametric analysis in both abnormal and normal conditions. This activation was formally confirmed by a conjunction analysis. This medial-lateral dissociation in the OFC to reward and punishment has been observed in previous studies (O'Doherty et al., 2001; Kringelbach 2005, for a review). According to this theory, medial OFC is related to monitoring the reward value, whereas lateral OFC activity is related to the evaluation of punishers that can lead to a change in behaviour. In these studies the right lateral OFC is invariably implicated, but rarely the left. In our study we found activations that match this theory.

Normal and abnormal conditions is modulated by different memory sub-system in aesthetic processing

In the parametric analysis two areas correlated with increasing preference for abnormal conditions, namely bilateral inferior frontal gyrus corresponding to BA 45 and another region where the centre of activation was located within the frontomedian cortex/frontal pole (BA 9/10). The latter region has been related to introspective evaluation of internal mental states, i.e. one's own thoughts and feelings (Christoff et al., 2000), and tasks that require self-reference (Gallagher et al., 2000; Gusnard et al., 2001). The former area has been implicated in "oddball"-tasks (Strange et al. 2000). Thus the frontomedian cortex is co-active with the inferior frontal gyrus in aesthetic evaluation tasks for stimulus material that violates expectancy based on previous experience. Specifically, activation of the inferior frontal gyrus may be involved with decoding of stimuli, whereas the frontomedian cortex may modulate evaluation of internally generated information.

In contrast, we found posterior cingulate activation in the parametric regression for increasing appeal in normal conditions. In opposition to abnormal conditions, this activation signifies a behavioural bias to use semantic or episodic memory to guide aesthetic preference where subjects may have attributed aesthetic judgments according to how familiar they were. Indeed the posterior cingulate has in the literature been related to successful memory retrieval (Cabeza et al., 2000; Fletcher et al., 1995). Accordingly, to evaluate stimulus material that does not violate expectation, i.e. normal conditions, all relevant information might be derived directly from the stimulus itself without explicit reference to one's own thoughts and feelings. This interpretation finds resonance in our contextual contrasts, i.e. normal conditions do not activate ToM areas.

These results show that aesthetic judgments recruit different memory sub-system for normal and abnormal conditions. Thus memory related processes guide aesthetic judgments. A potential fruitful consequence of this associability of stimulus material in aesthetic judgments would be to develop

standardized stimuli, where the variance is only altered in one dimension (e.g. spatial frequency) while other dimensions are held constant, which would control for memory components in order capture the basic network of areas involved in aesthetic judgments. This may be accomplished using Gabor patches.

In conclusion, we observed a difference between objects in normal context and objects in abnormal context, where normal conditions activated visual areas and no frontal areas, whereas abnormal conditions activated more significantly frontal regions. We evaluated this difference between abnormal and normal as the involvement of ToM in higher order oddball-tasks that require an interpretation. Thus, it seems evident that Magritte, unknowingly, used cerebral pathways that are distinct from those used by representational art, and unique to the movement of which Magritte was a protagonist, namely surrealist art. This furthermore supports the neuroaesthetic view that artists are in a sense intuitively experimenting with the laws about the organisation and functioning of the brain.

4.2 Experiment 2

4.2.1 Aims

It has been shown by several experiments that acquired expertise in general is associated with changes in the brain, sometimes even on a macro-anatomical scale. For example, in a study using a voxel-based morphometry analysis, Maguire and colleagues found that grey matter volume in the posterior hippocampus of London taxi drivers is greater than in age-matched controls, and that the size of this increase correlates positively with time spent taxi driving (Maguire et al. 1997).

Neuroimaging also demonstrates that musicians, after years of playing, react neurally different to musical inputs compared to non-musicians. For instance, in a recent functional magnetic resonance (fMRI) study, Bangert and colleagues compared brain activity in a group of musicians and non-musicians as they passively listened to a piano sequence and found elevated activity in the musicians in regions of the temporal lobe associated with auditory processing, and in frontal regions associated with motor control (Bangert et al., 2006). However, it is unclear if such a difference in perceptual or cognitive treatment of a stimulus also leads to a difference in aesthetic evaluation.

Imaging studies, where subjects' brain activity is correlated with subjective reports of preference, indicate that the parsing of subjective value and preference formation in relation to pleasant and unpleasant odours (Fulbright et al., 1998; Rolls et al., 2003), gustatory hedonics (Zald et al., 1998; Kringelbach et al., 2003), the attractiveness of human faces (Nakamura et al., 1998; Aharon et al., 2001) music (Blood et al., 2001) and paintings (Kawabata & Zeki 2004; Vartanian et al., 2004) primarily depends on a network of limbic and subcortical brain regions, including nucleus accumbens (NAcc), orbital frontal cortex (OFC), and the anterior cingulate cortex (ACC). We therefore found it of particular interest to investigate if expertise in a perceptual domain also implicates this system.

In order to accomplish this aim we recruited two groups of subjects, a group of architects and a group of non-architects, and scanned them in an

event-related fMRI paradigm as they rated pictures of buildings and human faces on an aesthetic scale. We surmised that architects and non-architects would respond differently to the pictures of buildings (because of the expertise effect) but not to pictures of faces, since earlier psychometric studies have found that people in different cultures, and of both sexes, on the whole agree on which faces are attractive (Langlois et al., 2000). Therefore, an expertise effect on the neural structures underlying the formation of an aesthetic judgment would be evident, if parts of the network mentioned above were activated differentially in the group of architect when judging buildings, but not when judging faces.

4.2.2 Methods

4.2.2.1 Subjects

Twenty-four subjects (11 experts/13 non-experts; 6 female experts/7 female non-experts, mean age experts 30.8 years, age range 26–42 years, mean age non-experts 27.2 years, age range 22–32 years, 4 left-handed) participated in the study. Two subjects (both non-experts, male) were excluded from the analysis; one due to clinical reasons, the other due to excessive head movement. Written informed consent from all subjects and ethical approval were obtained before the experiment. All had normal or corrected-to-normal vision, and none had a history of neurological or psychiatric disorders. Experts were recruited from architectural offices and schools of architectural education in Denmark where they were graduate or post-graduate students. Non-experts were all either undergraduate or graduate students. For non-experts we excluded subjects with a formal education in the humanities in order to increase the expertise-gap between the groups.

4.2.2.2 Stimuli and task

Visual achromatic stimuli belonging to two categories, buildings and faces, in total 336 stimuli, were selected from various online sources. 168 building stimuli

were selected from a larger collection of architecture. Prior to scanning the building-database was exposed to an aesthetic judgment scale in a behavioural pilot study by a separate cohort of subjects (7 experts; 3 females; mean age 34.3 years; age range 27–44 years. 6 non-experts; 3 females; mean age 29.2; age range 27–30 years). Level of appeal was rated using a scale from 1 to 5, where 1: “very unappealing” and 5: “very appealing”. Based on these results 168 building stimuli were selected that conformed to a relatively equal distribution for the rating scale. The surrounding of the building stimuli was shaded such that the building was in focus and central for each stimulus. This was accomplished in Photoshop (version 7.0, Adobe, USA). Any image noticeably distorted (e.g. proportion and illumination) by this process was excluded from the stimulus pool. Furthermore all building stimuli were subcategorised into two independent classes, viz. a formal or stylistic (‘modernist’ and ‘non-modernist’ architecture), and a typological (‘private buildings’, containing an equal distribution of types and scales of housing, and ‘public buildings’, also containing an equal distribution of scale and typology in order to control for a potential skewed preference distribution between the groups. This potential confound did not amount to any significant differences across all subjects during the scanning session ($n = 22$), and thus we do not comment further on this aspect. The buildings were presented with a resolution of 600 pixels in height and varying width with a maximum of 1024 pixels and equal luminance.

168 face stimuli were selected from a larger database of Caucasian faces (half female faces) that had been rated by a separate group of subjects ($n = 10$; 4 females; mean age 28.4; age range 26–30 years) for level of appeal in a behavioural pilot study prior to scanning. Level of appeal was rated using an identical scale as mentioned above. 168 faces were selected from the high, middle and low ends of the rating scale in order to obtain a balanced distribution. The face stimuli were masked to remove hair and were adjusted to be of equal size and luminance by using Photoshop (version 7.0, Adobe, USA). The faces were centred in a 588x600 pixel black background and presented at a screen resolution of 1024x768 pixels.

The experimental protocol consisted of an event-related design in which subjects were scanned while being presented with each of the 168 face stimuli and the 168 building stimuli in a pseudorandom order, making a total of 336 presentations. On each trial, a fixation cross was presented for 1000ms on a grey background followed by a stimuli presentation for 3000ms. Following the presentation of each stimuli subjects were instructed, within the 3000ms stimuli duration, to press one of five buttons on a response key-pad with their right hand to indicate their aesthetic judgment (1; very unappealing - 5; very appealing). Randomly interspersed with the stimuli presentations were 56 null event trials. Total scanning-time per subject was 26 min. in one session (fig. 16). Prior to scanning, subjects were informed that the study was concerned with investigating aesthetic judgments and subjects were instructed in the aesthetic judgment scale, but no reference was made to the experimental aims. After the scanning task was complete, subjects were, outside the scanner, presented with the stimuli again in which they rated each stimulus for familiarity.

Stimuli were presented and responses collected using E-prime (Psychology Software Tools, Inc.). The stimuli were back-projected via an LCD projector onto a transparent screen positioned over the subjects' head and viewed through a tilted mirror fixed to the head coil.

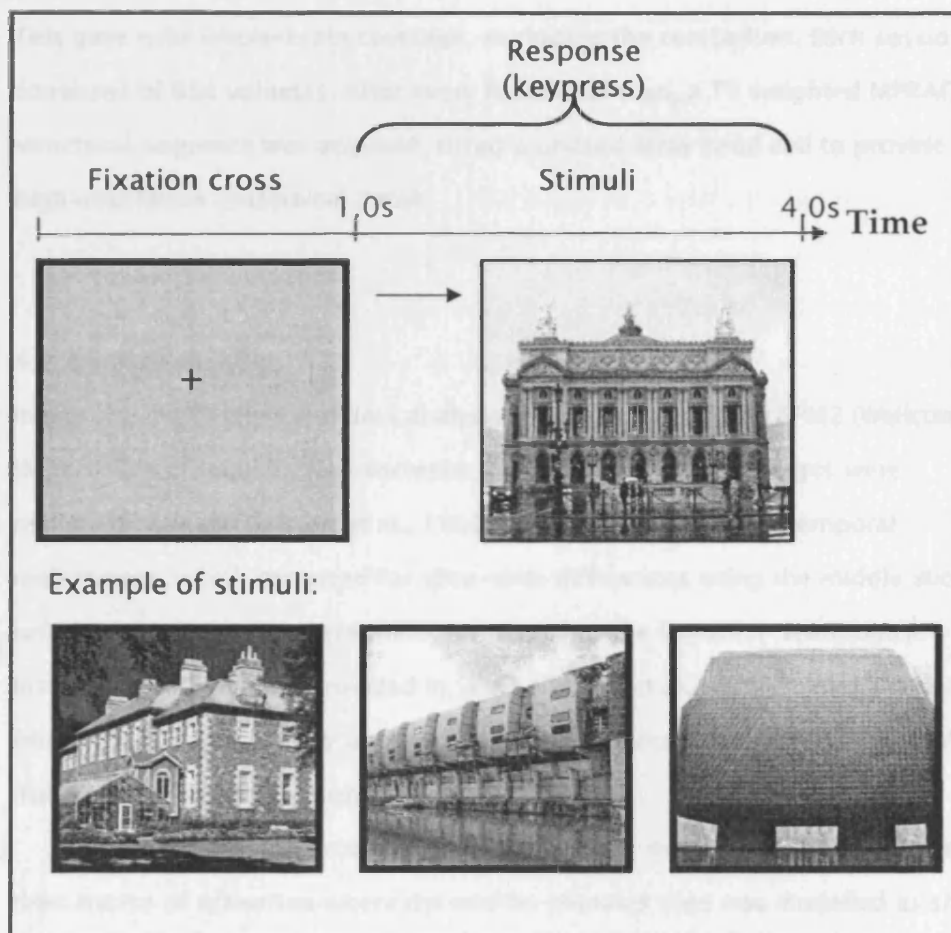


FIG. 16 Stimulus presentation paradigm. At the beginning of each trial a fixation cross was shown for 1000ms followed by stimulus presentation for 3000ms in which the subjects were instructed to press a key to indicate their aesthetic judgment (1–5). Examples of stimuli used during the scanning session are shown.

4.2.2.3 Data acquisition

The functional imaging was conducted by using a 3 Tesla scanner (Siemens, Magnetom Trio, Erlangen, Germany) to acquire gradient T2* weighted echo planar images (EPI) to maximise the blood oxygen level-dependent (BOLD) contrast (TE, 30ms; TR, 2400ms). The EPI sequence was optimised in order to reduce signal drop-out in OFC (Deichmann et al., 2003). Each functional image was acquired in an interleaved way beginning with 2nd slice (slice no. 2,4...40, 1,3...39) when counted from the bottom slice comprising 40 axial slices each 3.0mm thick, consisting of 64x64 voxels with an inplane resolution of 3x3mm.

This gave near whole-brain coverage, excluding the cerebellum. Each session consisted of 654 volumes. After every functional scan, a T1 weighted MPAGE structural sequence was acquired, using a phased array head coil to provide high-resolution anatomical detail.

4.2.2.4 Data analysis

Image pre-processing and data analysis was performed using SPM2 (Wellcome Department of Imaging Neuroscience, London, UK). The EPI images were realigned spatially (Friston et al., 1995c). This was followed by temporal realignment, which corrected for slice-time differences using the middle slice as reference slice. Images were then normalized to the Montreal Neurological Institute (MNI) template provided in SPM2 (Friston et al., 1995c). Finally a spatial filtering was performed by applying a Gaussian smoothing kernel of 8mm FWHM (full width at half-maximum).

Following pre-processing a general linear model was applied to the time course of activation where the middle stimulus time was modelled as single impulse response functions and then convolved with the canonical haemodynamic response function (HRF) including its temporal and dispersion derivatives in order to capture small variations in the onset and width of the BOLD responses.

A parametric regression analysis was used (see Buchel et al., 1998) that allowed us to model linear and non-linear parametric response profiles using orthogonalized polynomial expansion functions. This was performed for each of the two stimulus conditions using subject-specific aesthetic judgments in order to model a potential parametric modulation of aesthetic judgments. First-level analysis was performed on each subject to generate a single mean parameter corresponding to each term of the polynomial expansion. The six realignment parameters obtained during the realignment pre-processing stage were also modelled as nuisance variables, and entered into the design matrix as regressors

of no interest. For the analysis we also applied a high pass filter with a cut-off frequency at 1/128 Hz.

The statistical parametric maps from subject-specific data were entered into a second-level, random effects (RFX) analysis accounting for the between subject variance. Experts and non-experts were treated as separate groups in an ANOVA model using the beta-estimates of the two groups and the two stimuli conditions for the linear and the quadratic expansions. Equal variance was not assumed thus SPM2's options for non-sphericity correction was applied (Glaser & Friston, 2003).

Using t-contrasts allowed us to test for correlations of the fMRI BOLD signal and the parameters of interest performed respectively as linear and non-linear parametric modulations.

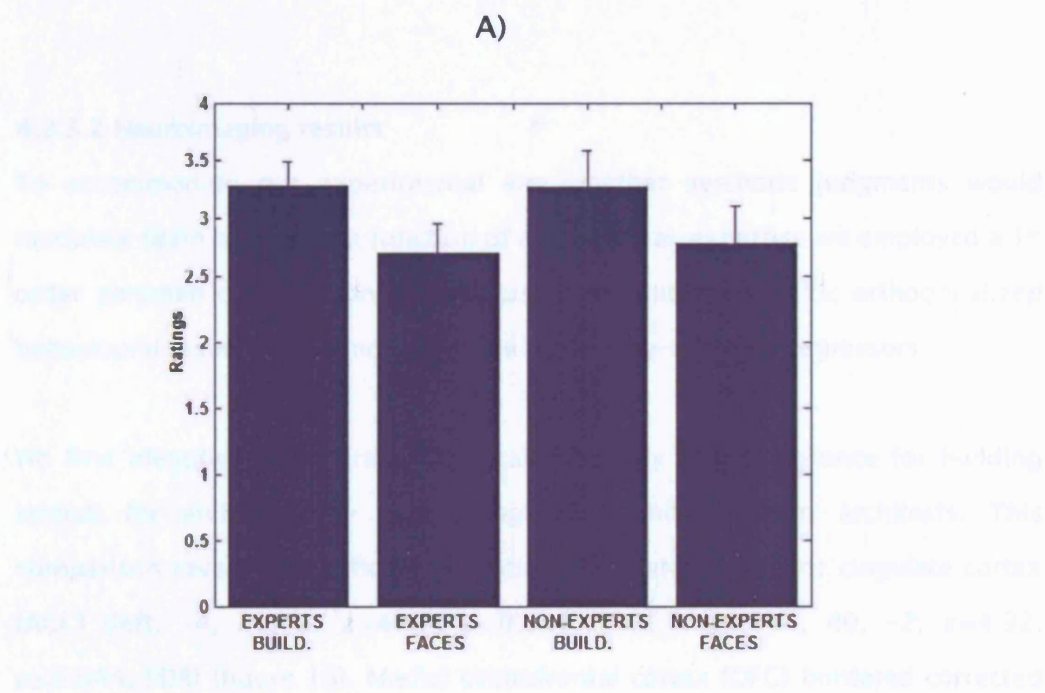
Reported p values are controlled for false discovery rate (FDR correction, Genovese et al., 2002), unless otherwise mentioned. The coordinates of all activations are reported in MNI space.

4.2.3 Results

4.2.3.1 Behavioural results

We first inspected the two groups' behavioural responses, collected during scanning, vis-à-vis the two stimulus types (figure 17). The average subject-specific aesthetic responses did not reveal significant differences between the two groups, but an ANOVA revealed significant differences between stimulus conditions (building and faces; $F(3,40) = 13.43$; $P < 0.000003$). The average rating for building stimuli for experts was 3.29 (SE=0.31) and for non-experts 3.28 (SE=0.32). For face-stimuli the average rating for experts was 2.7 (SE=0.25), while for non-experts it was 2.79 (SE=0.33) (figure 17). Response latencies between groups and stimulus types did not differ significantly ($F(3,40) = 1.48$; $P < 0.23$) (figure 17).

On itself this result naturally cast doubt on our hypothesis that the two groups' responses should be modulated by expertise. However, as our fMRI data could prove a more sensitive predictor of preference behavioural than our psychometric measure, we next analysed the Blood Oxygen Level Dependent (BOLD) signal associated with subjects' behavioural responses.



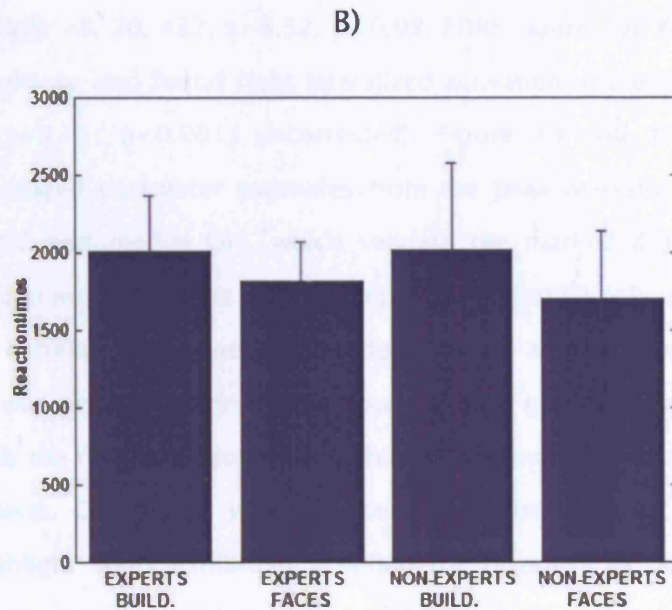


FIG. 17. Behavioural responses collected during scanning. (A) Mean aesthetic ratings for the two conditions and both subject groups. (B) Mean reaction times for the stimulus conditions and subject groups. The reaction times (RT) were averaged for each subject in each group and each condition, independent of the response given, and then averaged over all subjects in each group. Examination of these behavioural data in the two subject groups revealed that average RT for building stimuli for experts to be 2003 ms (SE = 357.4 ms) and for non-experts 2011 ms. (SE = 562.4 ms). Likewise the average response time for face stimuli for experts was 1810 ms (SE = 256.6 ms) and for non-experts 1696 ms. (SE = 440.4 ms).

4.2.3.2 Neuroimaging results

To accommodate our experimental aim whether aesthetic judgments would modulate brain activity as a function of architectural-expertise we employed a 1st order parametric regression analysis using the subject-specific orthogonalized behavioural responses by modelling four group-by-stimulus regressors.

We first identified brain areas that scaled linearly with preference for building stimuli for architects by subtracting non-architects from architects. This comparison revealed significant activations in bilateral anterior cingulate cortex (ACC) (left: -4, 30, 2; $z=4.47$; $p<0.041$, FDR. Right: 14, 40, -2; $z=4.32$; $p<0.044$, FDR) (figure 18). Medial orbitofrontal cortex (OFC) bordered corrected

threshold (left: -8, 30, -22; $z=3.52$; $p<0.08$, FDR) (figure 19). When we lowered the threshold we also found right lateralized activation of medial OFC (right: 6, 36, -12; $z=3.15$; $p<0.001$, uncorrected). Figure 18 and 19 describes the subject-averaged parameter estimates from the peak activations at the group level in ACC and medial OFC which validate the marked difference between architects and non-architects for building stimuli. Interestingly, ACC approached a positive correlation with aesthetic judgments for architects while it for non-architects was negatively correlated. However both groups correlated positively in OFC, only the response profile for architects was more significant compared to non-architects. Conversely, when we performed the opposite contrast, which should highlight areas exhibiting a parametric response to buildings in non-architects compared to architects, we found that no areas correlated significantly with such a response profile.

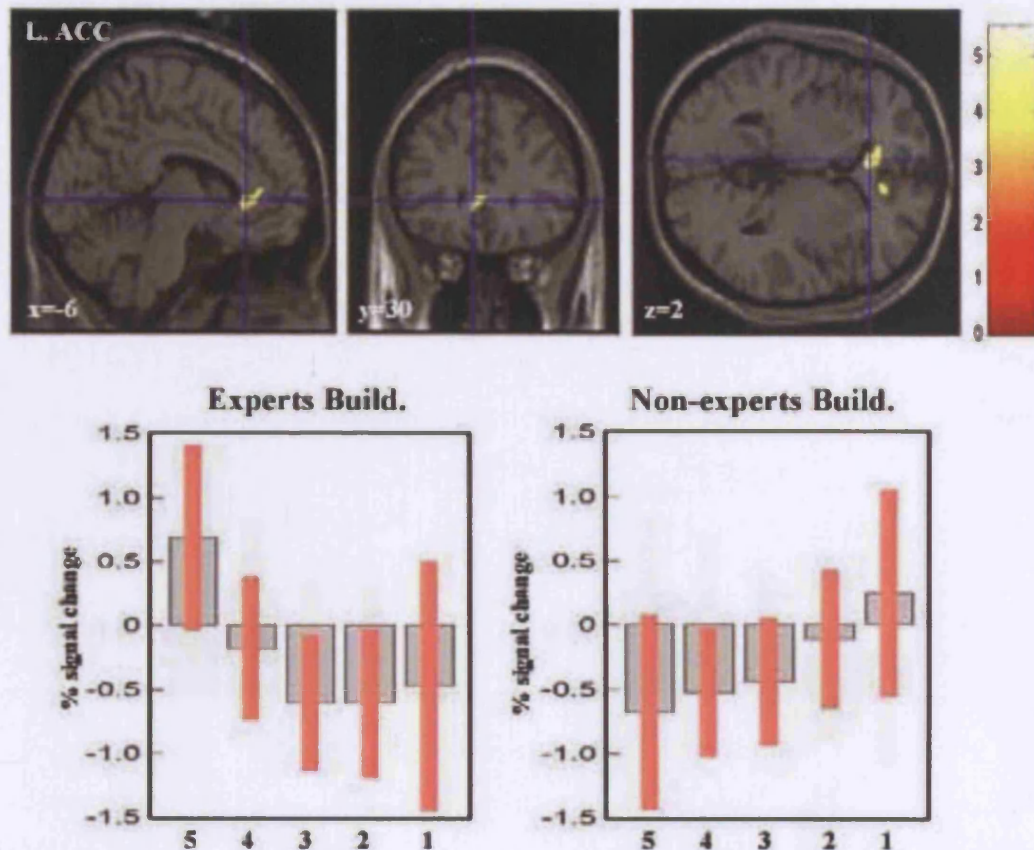


FIG. 18. The subtraction [Experts - Non-expert] for buildings for the 1st order term revealed significant voxels at $p < 0.041$, FDR in bilateral ACC. The activation is overlaid on a sagittal, coronal and axial sections of the canonical SPM structural image. Lower panels shows parameter estimates for experts and non-experts for building-stimuli from the hottest voxels in the ACC. Horizontal bars reflect aesthetic ratings starting from the highest (5) to the lowest (1) rating.

We next investigated the potential for individual differences in brain activity for which the difference between the two groups is due to their shared versus the non-shared of subjects. Such potential differences in brain activity would render the interpretation that EXP. and NON-EXP. are biased by expertise difficult. Thus, we looked for brain areas that showed overlap with preference for face stimuli by subtracting architects from non-architects and the converse subtraction, non-architects from architects. Specifically for the subtraction [architects > non-architects] and the converse subtraction [non-architects > architects] we used the peak voxels from the building-specific contrast in OFC and ACC and applied Small Volume Corrections (SVC). However, we found no significant differences for

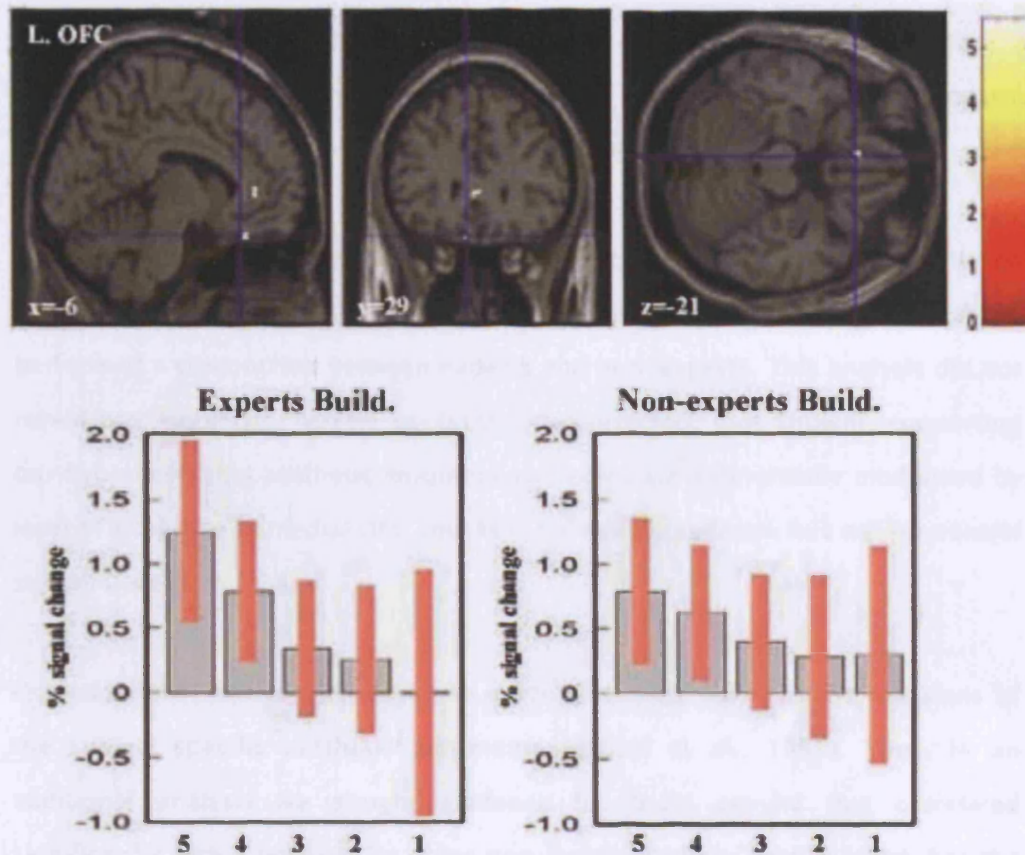


FIG. 19. The subtraction [Experts – Non-expert] for buildings for the 1st order term revealed significant voxels at $p < 0.08$, FDR in left medial OFC. The activation is overlaid on a sagittal, coronal and axial sections of the canonical SPM structural image. Lower panels shows parameter estimates for experts and non-experts for building-stimuli from the hottest voxels in the medial OFC.

We next investigated the control (face) stimuli to identify potential brain activity for which the difference between the responses to face stimuli varied across the two groups of subjects. Such potential differences in brain activity would render the interpretation that OFC and ACC is modulated by expertise difficult. Thus, we looked for brain areas that scaled linearly with preference for face stimuli by subtracting architects from non-architects and the converse subtraction, non-architects from architects. Specifically for the subtraction [architects > non-architects] and the converse subtraction [non-architects > architects] we used the peak voxels from the building-specific contrast in OFC and ACC and applied Small Volume Corrections (SVC). However, we found no significant difference for

both subtractions ($p < 0.001$, uncorrected). This result confirmed that expertise stimuli (buildings) but not control stimuli (faces) modulated the neural responses significantly as a function of expertise in ACC and medial OFC (figure not shown).

In order to formally identify possible common brain areas between groups that scaled linearly with preference responses for building stimuli we performed a conjunction between experts and non-experts. This analysis did not reveal any significant voxels ($p < 0.001^2$, uncorrected) (not shown), supporting our hypothesis that aesthetic judgment strategies are differentially modulated by level of expertise in medial OFC and ACC for building stimuli, but not for control stimuli (faces).

Our parametric design allowed us to model 2nd order polynomial expansions of the subject-specific aesthetic judgments (Buchel et al., 1998). Thus, in an additional analysis we sought evidence for brain activity that correlated significantly with a positive 2nd order non-linear response profile, which has the form of a u-shaped function to account for additional variance not captured by the 1st order linear term.

Interestingly, we did not observe any significant differences ($p < 0.001$, uncorrected) between the groups for two stimuli types for the 2nd order term. We therefore applied a conjunction analysis in order to look for common areas with a positive non-linear response profile for building stimuli regardless of group. One region in the ventral striatum, namely the left nucleus accumbens (NAcc) (-10, 10, -4; $z = 4.94$; $p < 0.018$, FWE) and also a small cluster in the left anterior thalamus (-14, -4, 12; $z = 4.75$; $p < 0.042$, FWE) was activated in the conjunction analysis at a very high threshold (see Figure 20). In order to further investigate the role of NAcc and anterior thalamus we were interested to see if this insensitivity to groups reflected in NAcc and anterior thalamus were also the case for both stimuli types. To this end a conjunction analysis including both stimuli types and both groups was engaged in a 4-way conjunction, but the result did not meet a corrected threshold. Thus we applied Small Volume Corrections (SVC)

using the clusters from the building-specific conjunction. Here we found that left NAcc (-10, 8, -4; $z=3.42$; $p<0.003$, SVC) was significantly activated, but left anterior thalamus did not survive SVC. Finally we replicated this analysis using the negative non-linear term, which has the form of an n-shaped function. However, this analysis did not result in any significant activations ($p<0.001$, uncorrected).

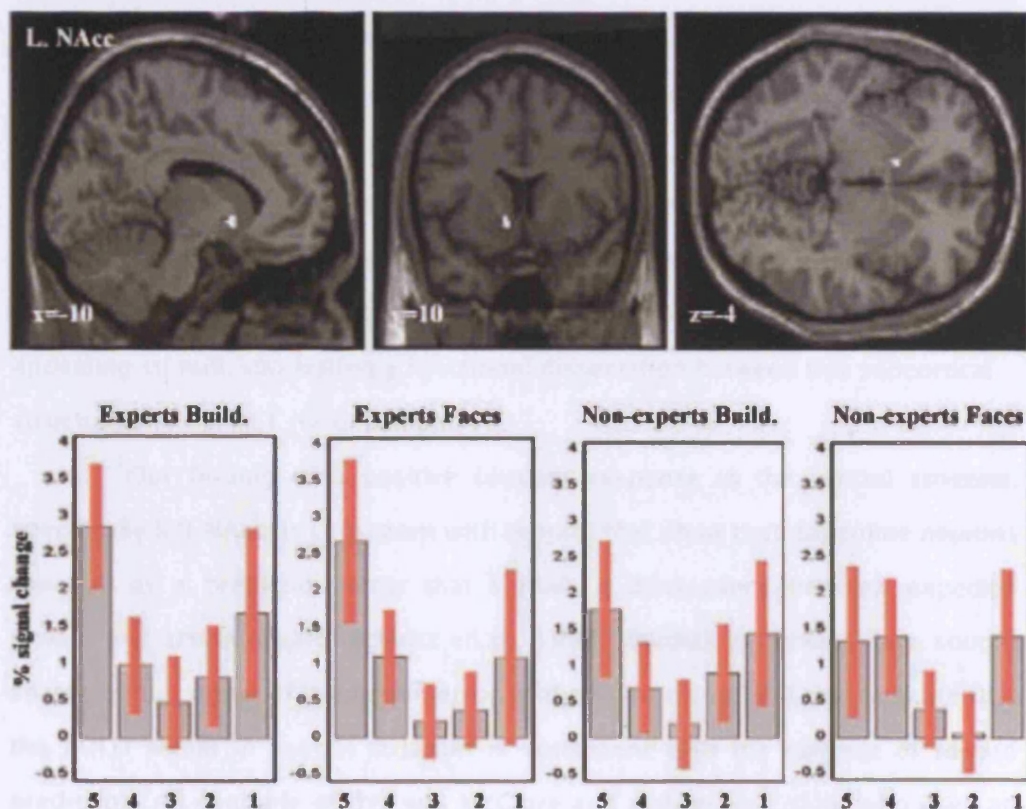


FIG. 20. The conjunction between experts and non-experts for building stimuli for the 2nd order term revealed significant voxels at $p<0.018$, FWE-corrected in left nucleus accumbens. The activation is overlaid on a sagittal, coronal and axial sections of the canonical SPM structural image. Lower panels shows parameter estimates for experts and non-experts for building-stimuli and face-stimuli.

4.2.4 Discussion

The presented data makes us advocate that architectural expertise modulates the neural response to buildings even in the absence of any aesthetic rating differences between experts and non-experts. Architectural expertise modulated the response only to buildings, but not to faces, indicating that the expertise effect is specific to the domain of their expertise, i.e. buildings.

The expertise modulated areas, the ACC and the medial OFC, have been implicated in other studies of aesthetic judgment. Thus, the present experiment demonstrates that expertise may not only impact on perceptual or cognitive system as has been previously shown (Bangert et al., 2006; Calvo-Merino et al., 2004; Maguire et al. 1997), but can also change the response profile of brain areas important for forming an aesthetic judgment. In contrast, activity in the left NAcc was enhanced in both group in response to strongly appealing and non-appealing stimuli, suggesting a functional dissociation between this subcortical structure and the ACC/OFC-complex.

Our finding of a positive bivalent response in the ventral striatum, specifically left NAcc, is consistent with reports that show that dopamine neurons function as a prediction error that signals a discrepancy between expected reward and actual reward (Schultz et al., 1997). Studies in humans have sought an analogous signal of prediction error in the brain using fMRI that indicate that the BOLD signal in ventral striatum is consistent with the concept of reward prediction. An example of this was McClure and colleagues (2003) who used an appetitive reward learning paradigm (delivery of juice) and showed that BOLD responses in the left striatum correlate with a prediction error. A negative prediction error caused by the absence of juice when it was expected correlated with a decreased BOLD response, while a positive prediction error (receiving juice when unexpected) correlated with an increased BOLD response. These findings fit with nonhuman primate findings by Schultz and colleagues, who showed that the firing of midbrain dopamine neurons which projects to the ventral striatum also conforms to the behaviour of the reward prediction error (Schultz et al., 1997). Thus, a positive prediction error is elicited when the environment behaves

better than expected (unexpected reward) and a negative signal for worse than expected (unexpected punishment). However, this evidence is not consistent with the observed bivalent positive u-shaped signal for both appealing and non-appealing stimuli in NAcc in this study. But it has been suggested that the striatum's role in reward processing is dependant on the saliency associated with reward rather than stimulus value (Zink et al., 2004). According to this account the reward prediction circuitry does not encode the reward and punishments per se, but rather a bivalent dimension according to unpredicted salient stimuli. Such a signal carries information about stimulus magnitude and the degree to which it was expected, but not about its valence. This interpretation is in keeping with the finding that blocking dopamine transmission, particularly in the ventral striatum (NAcc) in animals, diminishes the motivational salience of both appetitive as well as aversive reinforcers (Salamone et al., 1997). Thus, from the pattern of the results we observed, we can only conclude that there are regions within the ventral striatum that overlap in events that vary in reported value with positive (appealing) and negative (non-appealing) aesthetic judgments, which leave open the possibility that there may be non-overlapping populations or firing patterns that distinguish them.

The finding that ventral striatum responded in a u-shaped non-linear response profile, suggest that NAcc may encode the *relative value* of available stimuli, rather than coding for their *absolute value* as reflected by the 1st order linear polynomial response function in OFC and ACC. This observation is also compatible with another account of dopamine function in reward. The incentive motivation hypothesis (Berridge et al., 1998) implicates the dopamine system in reward expectancy, where dopamine neurons are argued to reflect the incentive or motivational value of a future reward, reflected in the degree to which an animal will work for reward, which correspond to a subjective state of 'wanting'. According to this theory, the 'wanting' component of reward is dissociable from the 'liking' or hedonic aspects evident during reward consumption. It is interesting to note in this context that we show that the region responding to relative value (NAcc) is dissociable from regions responding to absolute stimulus

value (OFC, ACC). This finding contrasts with most other studies of reward function that have used primary reinforcers and monetary rewards.

If the ventral striatum (NAcc) is mostly involved in the prediction of salience or in coding relative values, the absolute coding of valence needs to be done elsewhere using that information to bias selection of actions. Since the OFC is known to receive both sensory inputs and efferents from reward structures it has been speculated that it may play an important role in multi-sensory integration and encoding of the reward value of the stimulus (Kringelbach, 2005). Neuroimaging studies have showed that the OFC monitors changes in reward value (O'Doherty et al., 2000) and is involved, in decision-making situations, in the comparison and evaluation of the predicted reward values of possible behavioural choices (Gottfried et al., 2003). Furthermore, OFC has also been implicated in the evaluation and report of subjective pleasantness (de Araujo et al., 2003). Hence, the OFC appears to be tracking the outcome of reward processing and underlie the hedonic experience of such outcomes. The ACC, on the other hand, not only receives input from thalamic and brainstem structures, but also from OFC and other prefrontal structures. It furthermore projects to the cingulate motor areas located in the cingulate sulcus. It has therefore been described as a locus for the integration of emotion with motor behaviour, in Tomás Paus' words providing it with the potential to 'translate intentions into actions' (Paus, 2001). Together, we speculate that the OFC-ACC complex plays a pivotal role in mediating between preference formation and behavioural choices.

In conclusion, we have shown that the OFC-ACC complex plays a pivotal role in mediating between preference formation and behavioral choices, and importantly we have shown that experts and non-experts employ these structures differentially for the purpose of assessing the aesthetic value of buildings.

4.3 Experiment 3

4.3.1 Aims

The experiments documented in this thesis have been concerned with aesthetic perception and processing, and its hedonic or affective component involved. The two experiments that precede this experiment in this thesis, and in other studies from our lab (Kawabata and Zeki, 2004), have demonstrated that the valence of a given visual stimulus is represented in particular in medial OFC. More specifically, stimuli that are rated as aesthetically appealing (positive hedonic value) preferentially activate medial OFC (experiment 1 and 2), whereas aesthetically unappealing stimuli (negative hedonic value) activate more lateral regions of the OFC (experiment 1).

The aim of this fMRI study was to measure the effects of cognitive (semantic) information on the neural responses to aesthetic judgments of a stimulus material consisting of abstract artworks. The design consisted of presenting abstract artworks together with a word label at the bottom of the screen. The stimulus material was labelled on different trials as either belonging to the Louisiana Museum of Modern Art in Denmark ("Louisiana" label), or as computer generated artworks ("Computer" label) made by the experimenter. This was the instruction given to the subjects; however the stimulus material used, i.e. the abstract artworks were all original non-canonical abstract artworks that neither were computer-generated replicas or belonged to Louisiana Museum of Modern Art. This design allowed us to assess how perception and hedonic value is being altered and modulated as a function of the word labels applied by performing correlation analyses with the subjective aesthetic ratings between the two different experimentally manipulated conditions.

Although it is likely that humans will rate aesthetically appealing stimuli highest and unappealing stimuli lowest, it however remains a possibility that top-down influences act to organize coherent behavioural preference. Our hypothesis was that it is the subjects' conception of the object/stimulus, rather than the sensory properties of the stimulus, that primarily determine its hedonic value. This aspect also speaks to a long standing question within philosophical

aesthetics. It has been argued that no object is inherently a work of art. Rather it is the institutional context (i.e. art museums) artworks appear in that makes us experience objects as art (Danto, 1964). In terms of this experiment this is tantamount to stating that objects must be labelled as art in order to be experienced as art.

4.3.2 Methods

4.3.2.1 Subjects

Fourteen subjects (5 females; mean age 26,3 years, age range 23–29 years, 4 left-handed) participated in the study. Written informed consent from all subjects and ethical approval were obtained before the experiment. All had normal or corrected-to-normal vision, and none had a history of neurological or psychiatric disorders. Subjects were all fully educated undergraduate or graduate students. We excluded subjects with a formal education in any art-related field in order to reduce the familiarity effect of the stimulus class.

4.3.2.2 Stimuli and task

Visual chromatic reproductions of abstract paintings were used as stimuli, in total 200 stimuli were selected from various online sources. Prior to scanning the stimuli were exposed to an aesthetic judgment scale in a behavioural pilot study by a separate cohort of subjects (6 subjects; 3 females; mean age 25.3 years; age range 24–28 years). Level of appeal was rated using a scale from 1 to 5, where 1: “very unappealing” and 5: “very appealing”. Based on these results we found that the 200 stimuli conformed to a relatively equal distribution in relation to the rating scale. The stimuli were presented at a screen resolution of 1024x768 pixels, and centred in a 500x500 pixel resolution surrounded by a grey background.

All 200 stimuli were reproductions of original non-canonical abstract artworks and was thus a homogeneous database of stimuli. However under each

stimuli we manipulated the 200 homogeneous stimuli by applying one of two labels in different blocks; half of the stimuli were labelled as “Louisiana” (a famous art museum in Denmark) while the other half of the stimuli were labelled as “Computer” (implying that the experimenter made the stimuli in Photoshop). All labels were presented in a pseudorandom order and counterbalanced across subjects. Prior to scanning, subjects were informed that the study was concerned with investigating aesthetic judgments and subjects were instructed in the aesthetic judgment scale, but no reference was made to the experimental aims. Subjects were given the following instruction: *“Inside the scanner you will be presented with 200 abstract paintings. There are two types of paintings. One half of the paintings, that is 100, we have taken from the Louisiana Museum of Modern Art (Copenhagen, Denmark). The other half has been generated by the experimenter by using a computer programme (Photoshop) in such a way as to mirror the ones we have borrowed, although they are not exact copies. Your task is to tell us how much you like the 200 paintings by rating them on a scale from 1 to 5, where “5” is those paintings you really like, and “1” is the paintings you really dislike. We are only interested in your own personal, subjective experience, so please don’t speculate about how we would judge the paintings”.*

The experimental protocol consisted of a block-design with 5 presentations in each block with identical labels making it a total of 20 blocks of “Louisiana” labelled blocks, and 20 blocks labelled “Computer”. On each trial, a fixation cross was presented for 1000ms on a grey background followed by a stimuli presentation for 5000ms. Following the presentation of each stimuli subjects were instructed, within the 5000 ms stimuli duration, to press one of five buttons on a response key-pad with their right hand to indicate their aesthetic judgment (1; very unappealing – 5; very appealing) (fig. 21). Total scanning-time per subject was 20 min. in one session. After the scanning was complete, subjects were, outside the scanner, presented with the stimuli again where they rated each stimulus for familiarity.

Stimuli were presented and responses collected using E-prime (Psychology Software Tools, Inc.). The stimuli were back-projected via a LCD

projector onto a transparent screen positioned over the subjects' head and viewed through a tilted mirror fixed to the head coil.

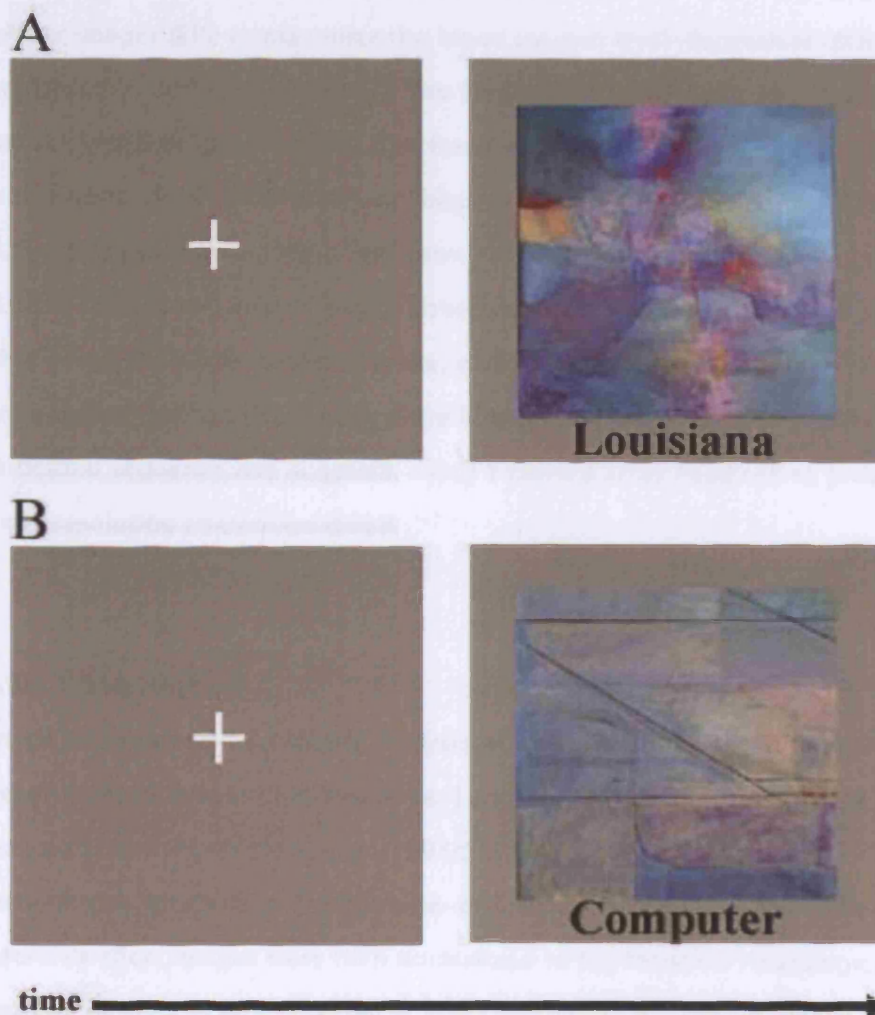


FIG. 21. The experimental protocol where a fixation was shown for 500ms followed by a block of 5 presentations of Louisiana labelled trials (A) or Computer labelled trials (B), which was presented for 5000ms in which subjects were instructed to rate the level of aesthetic appeal on a scale from 1–5.

4.3.2.3 Data acquisition

The functional imaging was conducted by using a 3 Tesla scanner (Siemens, Magnetom Trio, Erlangen, Germany) to acquire gradient T2* weighted echo planar images (EPI) to maximize the blood oxygen level-dependent (BOLD) contrast (TE, 30ms; TR, 2400ms). The EPI sequence was optimized in order to reduce signal drop-out in OFC (Deichmann et al., 2003). Each functional image was acquired in an interleaved way beginning with 2nd slice (slice no. 2,4...40, 1,3...39) when counted from the bottom slice comprising 40 axial slices each 3.0mm thick, consisting of 64x64 voxels with an inplane resolution of 3x3mm. This gave near whole-brain coverage, excluding the cerebellum. Each session consisted of 500 volumes. After every functional scan, a T1 weighted MPRAGE structural sequence was acquired, using a phased array head coil to provide high-resolution anatomical detail.

4.3.2.4 Data Analysis

Image pre-processing and data analysis was performed using SPM2 (Wellcome Department of Imaging Neuroscience, London, UK). The EPI images were realigned spatially (Friston et al., 1995c). This was followed by temporal realignment, which corrected for slice-time differences using the middle slice as reference slice. Images were then normalized to the Montreal Neurological Institute (MNI) template provided in SPM2 (Friston et al., 1995c). Finally a spatial filtering was performed by applying a Gaussian smoothing kernel of 8mm FWHM (full width at half-maximum).

Following pre-processing a general linear model was applied to the time course of activation where the stimulus onset was modelled as single impulse response functions including stimulus duration (5000ms) and then convolved with the canonical haemodynamic response function (HRF) including its temporal and dispersion derivatives in order to capture small variations in the onset and width of the BOLD responses.

A parametric regression analysis was used (see Buchel et al., 1998) that allowed us to model 0th order, 1st order and 2nd order haemodynamic responses using orthogonalized polynomial expansion functions. This was performed for each of the two conditions (Louisiana and Computer labels) using subject-specific aesthetic judgments in order to model a potential parametric modulation of aesthetic judgments for the 1st order and 2nd order expansions. The 0th order parametric analysis allowed us to model the two labelling conditions independent of the aesthetic judgment. First-level analysis was performed on each subject to generate a single mean parameter corresponding to each term of the polynomial expansion. The six realignment parameters obtained during the realignment pre-processing stage were also modelled as nuisance variables, and entered into the design matrix as regressors of no interest. For the analysis we also applied a high pass filter with a cut-off frequency at 1/128 Hz.

The statistical parametric maps from subject-specific dataset were entered into a second-level, random effects (RFX) analysis accounting for the between subject variance. An ANOVA model using the beta-estimates of the two conditions for the 0th, 1st and 2nd order expansions was applied. Equal variance was not assumed thus SPM2's options for non-sphericity correction was applied (Glaser & Friston, 2003).

Using t-contrasts allowed us to test for correlations of the fMRI BOLD signal and the parameters of interest performed respectively as 0th order, 1st order and 2nd order parametric modulations.

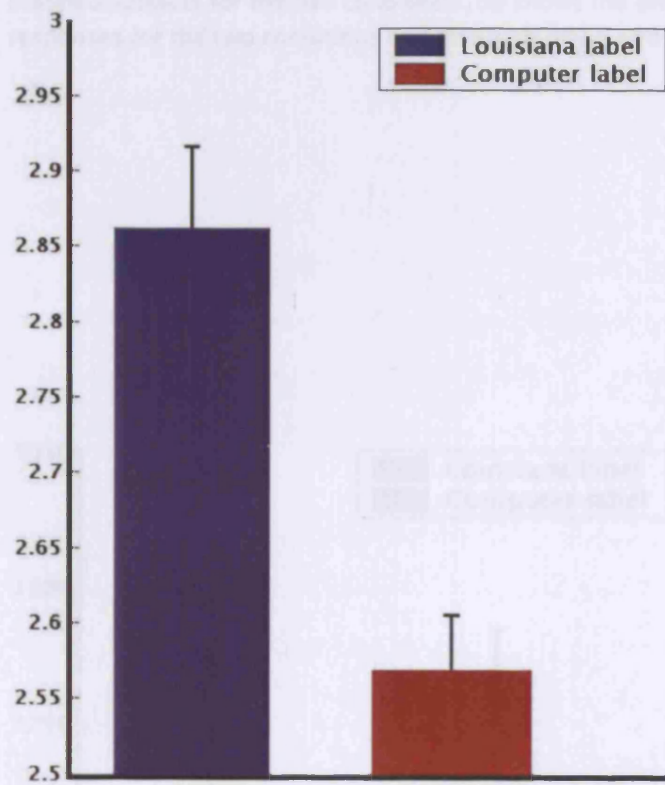
Reported p values are controlled for false discovery rate (FDR correction, Genovese et al., 2002), unless otherwise mentioned. The coordinates of all activations are reported in MNI space.

4.3.3 Results

4.3.3.1 Behavioural results

The subject averaged aesthetic ratings collected during scanning for the two stimulus conditions are shown in figure 22. The figure shows that the stimuli when labelled "Louisiana" was rated as being on average 2.86 (SEM=0.05) and when labelled "Computer" was on average rated as being 2.57 (SEM=0.07). Interestingly, statistical analysis revealed that the stimuli was rated as being significantly more aesthetically pleasing when labelled as "Louisiana" than when labelled as "Computer" (paired $t = 4.21$; $df = 13$; $p < 0.001$). Subject-averaged reaction times (RT) for stimuli when labelled as "Louisiana" was 1224ms (SEM=98.5) and 1187ms (SEM=96.5) when labelled as "Computer" (figure 23). The labels did produce a small but nevertheless significant difference in (RT) (paired $t = 2.23$; $df = 13$; $p < 0.044$), such that subjects responded quicker when the label was "Computer" compared to when the label was "Louisiana".

A)



B)

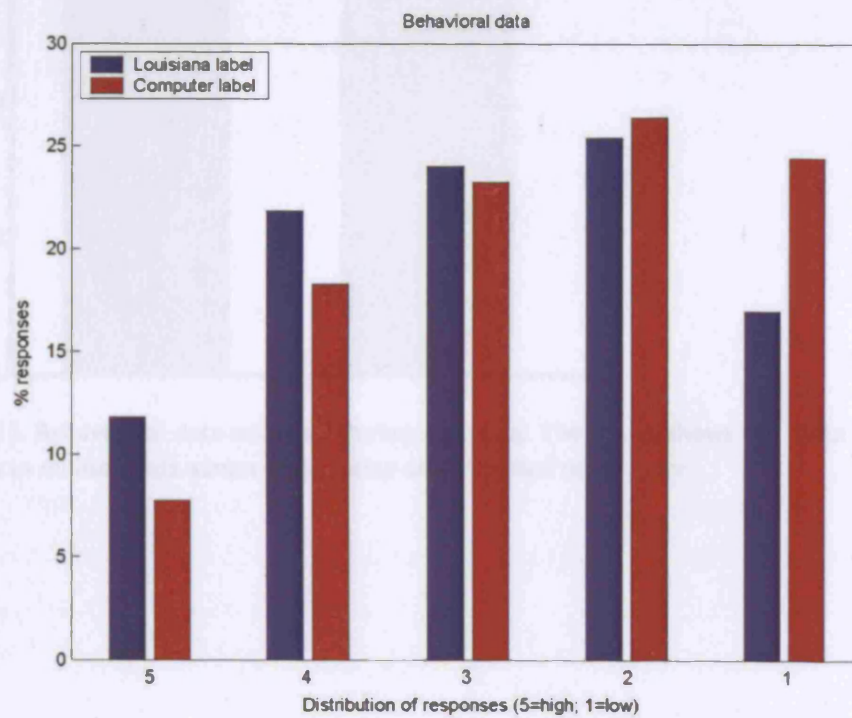


FIG. 22 Behavioural data collected during scanning. (A) Mean aesthetic ratings across all scanned subjects for the two conditions. (B) shows the distribution of the aesthetic responses for the two conditions and standard mean error.

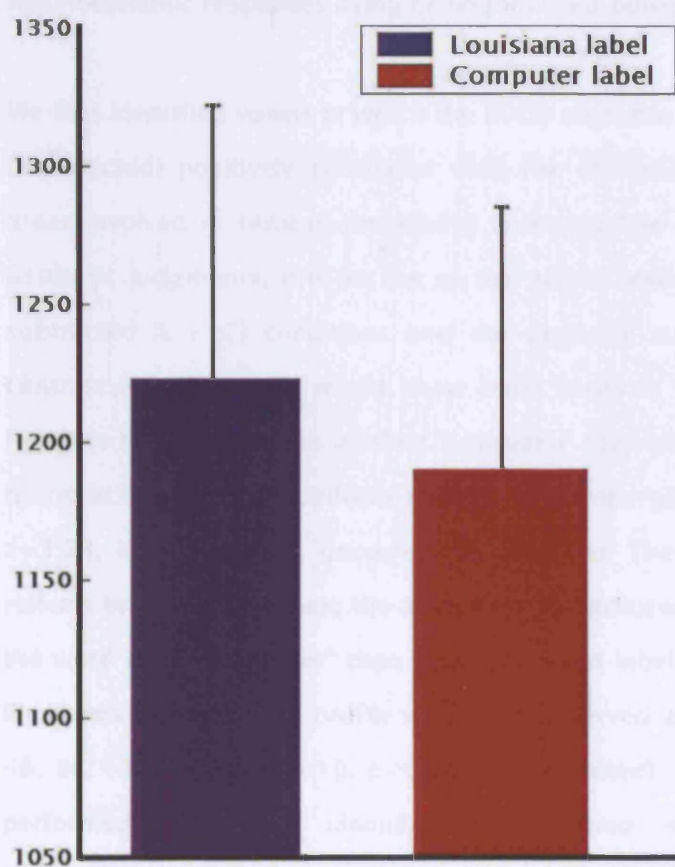


FIG. 23. Behavioural data collected during scanning. The figure shows the mean reaction-times in milliseconds across all subjects and standard mean error.

4.3.3.2 Neuroimaging results

To accommodate our experimental aim whether aesthetic judgments would differentially modulate brain activity due to the labelling of the two conditions we employed a parametric regression analysis using the subject-specific orthogonalized behavioural responses. Parametric designs have proven valuable in exploring relationships between systematically varying experimental parameters and physiological responses (Buckner et al., 1998). The parametric regression analysis allowed us to model 0th order, 1st order and 2nd order haemodynamic responses using orthogonalized polynomial expansion functions.

We first identified voxels in which the BOLD response was significantly ($p < 0.001$, uncorrected) positively correlated with the 0th-order regressor which reflects areas involved in sensory processing and cognitive processing associated with aesthetic judgments, irrespective of the actual aesthetic rating given. Thus we subtracted [L - C] conditions and the opposite subtraction [C - L]. For the contrast [L - C], which would show brain areas in which more activation was found to the stimuli when labelled "Louisiana" than when labelled "Computer", we found activity in left lentiform nucleus (putamen/globus pallidus) (-16, 2, -6; $z = 3.23$; $k = 6$; $p < 0.001$, uncorrected). (fig. 24). The converse contrast [C - L] reflects brain activity where the activation was influenced to a stronger degree by the word label "Computer" than when the word label was "Louisiana". Figure 25 illustrates this response profile where we observed activity in left lateral OFC (-48, 36, -12; $z = 3.22$; $k = 10$; $p < 0.001$, uncorrected). A conjunction analysis was performed to formally identify areas involved in the aesthetic judgment irrespective of whether the information was labelled L or C. However, this conjunction did not result in significant activity ($p < 0.001^2$, uncorrected). These results thus reflect effects of the word label which would seem to influence the aesthetic judgment of what was perceived even when there was no change in the stimulus for the two conditions.

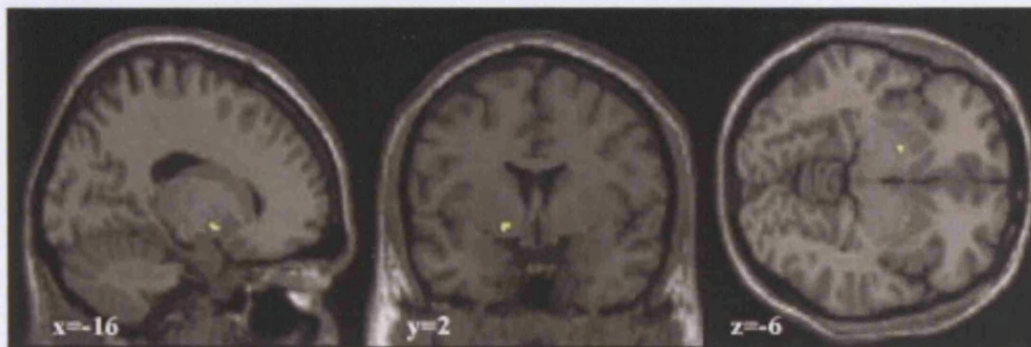


FIG. 24. The subtraction [L - C] for the 0th order term revealed significant voxels at $p < 0.001$, uncorrected in left lentiform nucleus. The activation is overlaid on a sagittal, coronal and axial sections of the canonical SPM structural image.

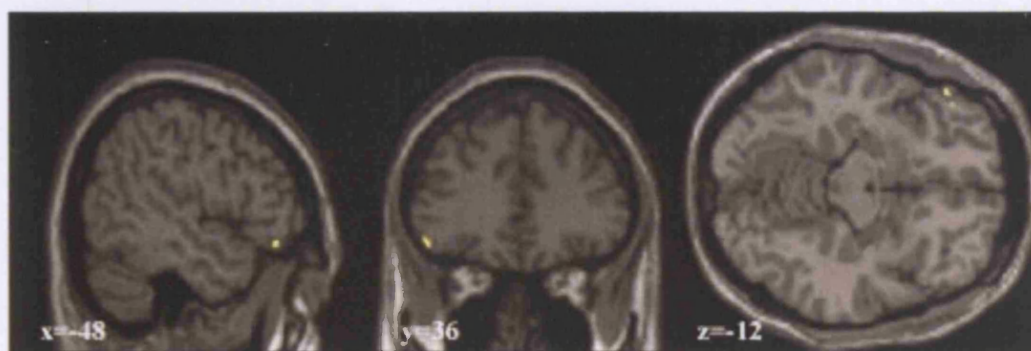


FIG. 25. The subtraction [C - L] for the 0th order term revealed significant voxels at $p < 0.001$, uncorrected in left lateral OFC. The activation is overlaid on a sagittal, coronal and axial sections of the canonical SPM structural image.

We next correlated the BOLD signal with the linearly increasing aesthetic judgments when the stimulus material was labelled as L and as C, which represents the 1st order term in the parametric regression analysis. A significant correlation was observed in a cluster in right medial OFC for the subtraction [L - C] (12, 48, -20; $z = 4.37$; $k = 19$; $p < 0.01$, FDR) (fig. 26). When we lowered the threshold ($p < 0.001$, uncorrected) we also found activity in left frontal pole on the ventral aspect of the medial prefrontal cortex (VMPFC) (-10, 60, 2; $z = 3.49$; $k = 15$, $p < 0.001$) (fig. 27). Figure 26 describes the subject-averaged parameter estimates from the peak activation at the group level in right medial OFC. The

parameter estimates validate the significant difference in ratings being given during scanning showing an influence by the word labels as shown in figure 22. Conversely, when we correlated the linearly increasing aesthetic judgments with the BOLD signal for the contrast [C - L] we found that no areas correlated significantly with such a response profile ($p < 0.001$, uncorrected) (figure not shown). A conjunction was performed to identify potential common brain regions for the 1st order linear regression analysis. This analysis did not reveal significant voxels ($p < 0.001^2$, uncorrected) (not shown) confirming that aesthetic judgment strategies are differentially modulated by the two labels. In line with our initial hypothesis, this result suggest that subjects when asked to perform an aesthetic judgment of stimulus conditions with L labels, elevated activity is seen in right medial OFC, which is not observed when the same subjects perform the same task on C labelled conditions.

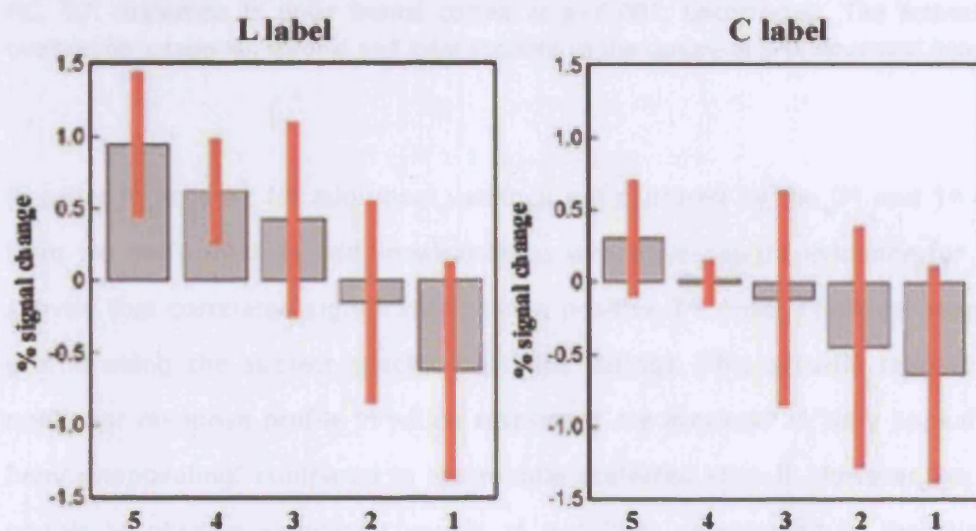


FIG. 26. Upper panel: Activation in medial OFC for the 1st order term significant at FDR. Lower panels: Parameter estimates for the hottest voxels in medial OFC for the two conditions Louisiana (L) and Computer (C). Horizontal bar reflects aesthetic ratings from 'very appealing' (5) to 'very unappealing' (1).

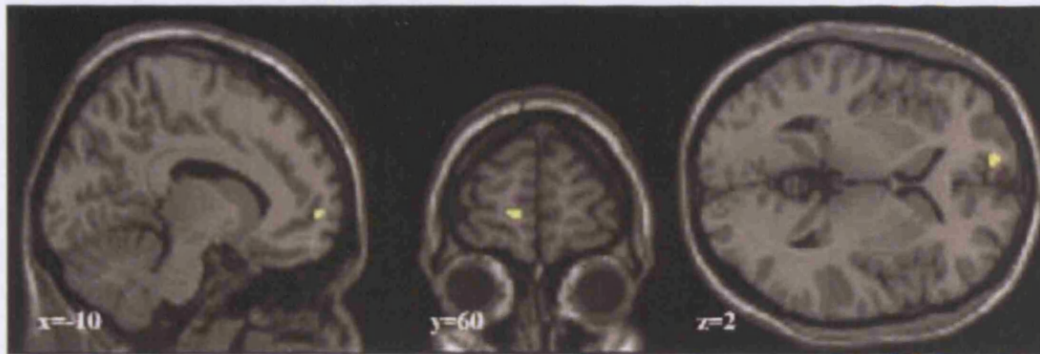


FIG. 27. Activation in polar frontal cortex at $p < 0.001$, uncorrected. The activation is overlaid on a sagittal, coronal and axial sections of the canonical SPM structural image.

In order to account for additional variance not captured by the 0th and 1st order term we performed an additional analysis where we sought evidence for brain activity that correlated significantly with a positive 2nd order nonlinear response profile using the subject-specific aesthetic ratings. This actually represents a nonlinear response profile in which responses are maximal at “very appeal” and “very unappealing” compared to the middle preferred stimuli. However, we were unable to observe significant voxels at $p < 0.001$, uncorrected to the stimulus material when labelled as “Computer” than when labelled as “Louisiana” ([L – C]) and for the opposite subtraction [C – L] (not shown). We applied a conjunction analysis in order to look for common areas with a positive nonlinear response profile for the two stimulus conditions, but the analysis did not result in significant activations at $p < 0.001$, uncorrected (not shown).

4.3.4 Discussion

The aim of this fMRI study was to show that a cognitive input, a word label, can modulate aesthetic ratings of an otherwise homogeneous stimulus material of abstract artworks in a homogeneous group of subjects with no formal training in the arts. We have in the psychophysics section shown a significant behavioural preference for stimuli presented with the label "Louisiana" than when the same stimulus is presented with the word label "Computer". Furthermore we have demonstrated a significant difference in RT, which interestingly demonstrate that subjects arrive at an aesthetic judgment when the label is "Computer" compared to when the label is "Louisiana ". Crucially, we have shown that this modulation of the aesthetic ratings on a behavioural level was correlated at a neural level with medial OFC when the label was "Louisiana" compared to when the label was "Computer", which suggest a modulation in medial OFC to cognitive input. Irrespective of the actual aesthetic ratings we have furthermore shown that the word label "Louisiana" results in differential brain activity in ventral striatum, specifically the lentiform nucleus. In contrast, we have shown that more activity was found in left lateral OFC when the stimulus material was labelled as "Computer" than when it was labelled "Louisiana".

The results demonstrate that cognitive and semantic inputs can be very important in influencing subjective behavioural ratings including responses to abstract artworks. The novelty of this study is that high-level semantic input such as word labels can modulate activity in sub-regions of the pre- and orbital part of the medial frontal cortex and ventral striatum.

The activation of medial OFC that was found to correlate with the aesthetic ratings given to the "Louisiana" labelled conditions coincides with the finding of experiment 1 and 2 in this thesis where the same region was found to correlate preferentially with the appealing but not the unappealing aesthetic ratings given. Thus the present finding in this study is in agreement with current evidence that the medial aspect of the human OFC represents the hedonic attributes involved in aesthetic judgments of various stimulus materials. But the

present finding also provides evidence that this representation holds even when the attributed hedonic properties are modulated by cognitive and semantic input.

The study described here is similar to the study by De Araujo and colleagues (2005), who found more activation in medial OFC when subjects were making hedonic judgments of a set of odours that were manipulated with a cognitive positive label in contrast to a negative word label. It has been established by psychophysical studies that olfactory discrimination is inefficient in humans, such that successful odour identification is highly susceptible to factors such as familiarity and the semantic connection between an odour and its name (Cain 1979). Based on this evidence it may not be surprising that De Araujo and colleagues found that verbal or semantic information can strongly influence the perception of odour attributes. It is however not well documented that semantic labels can influence aesthetic and hedonic ratings of artworks. However, Russell (2003) found an increase in the hedonic value from first to second ratings when abstract and semiabstract artworks were presented with title and the artist's name in the second phase. In the psychophysical section of the present study, we extend that observation by showing that manipulated semantic labels influence hedonic judgments even when there is no difference in the stimulus material, and furthermore found a neural correlate of this behavioural modulation in medial OFC, a region that overlap with that found by De Araujo and colleagues (2005). These results suggest that cognitive input, a words label, can influence brain activation in areas such as medial OFC.

A modulation of medial OFC to objects of varying reward value has also been found in other studies. For example Erk and colleagues (2002) found that cultural objects such as sports cars versus small cars modulate the reward circuitry in regions such as medial OFC, ventral striatum and bilateral prefrontal cortex. A similar study investigated the effect of cultural meaning on neural processing and found similar results. This study investigated flavour produced by respectively Coca-cola and Pepsi in which it was found that the rated preference of unlabelled drinks (i.e. without cognitive influences) was reflected in activations of a ventromedial part of the prefrontal cortex (VMPFC) and that pictures of

Coca-cola versus Pepsi cans influenced activations in areas that are more cognitive than flavour related areas, including hippocampus and dorsolateral prefrontal cortex (McClure et al., 2004). They were unable to image the OFC because of signal loss due to magnetic field inhomogeneities that often occur in this region (Deichmann et al. 2003). The activation of VMPFC reported by (McClure et al., 2004) overlap with the activation in our study, although we only observed this cluster at an uncorrected threshold ($p < 0.001$). The VMPFC is strongly implicated in signalling basic appetitive aspects of reward. BOLD signal changes in this region scale with reward value (Knutson et al., 2001a; O'Doherty et al., 2003c). The medial OFC and VMPFC has been shown to be strongly related and implicated in emotional processing (Lane et al., 1997), with increased responses to rewarding outcomes (O'Doherty et al., 2003a). The implication of these findings in the present study is that these areas may be engaged under conditions when behavioural decision making is required. This interpretation is compatible with the idea that the OFC and medial PFC are involved in integrating rewarding feedback for affective decision making (Bechara et al., 2000).

In contrast to the finding that medial OFC respond preferentially to linearly increasing aesthetic ratings, we found that ventral striatum, specifically lentiform nucleus respond solely to sensory information irrespective of the aesthetic ratings given when the label was "Louisiana" compared to when the label was "Computer". Numerous studies have identified the ventral striatum as critical in reward-related processing (Apicella et al., 1991; Schultz et al., 1993a) (for review, see Koob, 1992; Robbins et al., 1996). The nucleus accumbens has probably been most consistently related to reward, but responses have been observed throughout the ventral part of the striatum (Apicella et al., 1991; Schultz et al., 1993a). The region observed here is lateral and more posterior to the nucleus accumbens but falls clearly within the ventral striatum, although the activation could not be localized to either the putamen or the globus pallidus. Evidence suggests that ventral striatum is a crucial component of the dopaminergic projection system which accords with evidence of preferential responses in ventral striatum to appetitive rather than aversive stimuli

(Mirenowicz & Schultz, 1996). In animals these responses are to biologically salient reinforcers such as food and addictive drugs. Our findings suggest that the ventral striatum mediates effects of more abstract rewards such as abstract artworks that contain a positive (reinforcing) word label ("Louisiana").

Given this result, the obvious question arises, why the ventral striatum would be activated by the word label "Louisiana" significantly more than the label "Computer"? Responses in this region may reflect an increased expectation of reward associated with the label "Louisiana" rather than the label "Computer". This interpretation accords with animal studies that implicate globus pallidus in the expression of incentive motivation and reward expectancy (Schultz et al., 1992) and leads to an increase of ventral striatal activation (Knutson et al., 2001b). It thus remains a possibility that artworks with the label "Louisiana" function as a predictor of reward and thus co-notates artworks that have been exhibited at Louisiana Museum of Modern Art in contrast to artworks that are made on a "computer" and not been exhibited in an art museum.

Alternatively, as the ventral striatum in previous neuroimaging studies has been associated with motor control (Garraux et al., 2005), and given the differences in RT between L and C conditions, it might be plausible that the activation observed in ventral striatum reflects motor control as well as reward expectancy effects.

An interesting finding in this study is a dissociable pattern of responding in the ventral striatum compared with medial OFC and frontal pole. This response finds support in evidence from animal studies (Tremblay and Schultz, 1999; Watanabe, 1999) that suggest that patterns of neuronal firing associated with reward are different in striatal and OFC neurons. Although both regions contain neurons that respond during expectation and detection of reward, OFC neurons additionally code stimulus affective value. This dissociation of striatum and OFC has also been replicated in neuroimaging studies (O'Doherty 2002, 2003b; Berridge, 1996; Knutson et al., 2001a). The 0th order correlation in ventral striatum observed in this study is consistent with the proposal that this region is involved in expectation and detection of reward.

Unlike the other experiments in this thesis, we adopted a blocked rather than event-related approach in the experiment. An event-related study in which the labelling is varied would inevitably have introduced an element of unpredictability. Our approach in this study allowed us to look at responses to cognitive label ("Louisiana" and "Computer") that were fully predictable within blocks. This is an important point, because Breiter et al. (2001) have shown that responses to reward value are critically modulated by subjects' expectancy. However, by choosing the blocked approach, we are unable to specify whether the responses observed reflect reward expectancy, reward detection, or a combination of the two.

Conversely, significant correlations with the 0th order term, i.e. irrespective of the actual aesthetic rating given were observed at the left lateral OFC when the label was "Computer" compared to when it was "Louisiana". This results points to a dissociation between medial and lateral OFC that we also observed in experiment 1. In experiment 1 this dissociation was born out when making a correlation between a linear parametric response profile with increasing appeal, where we found medial OFC, and for decreasing appeal we found lateral OFC. A similar dissociation between medial and lateral OFC activity has been noted in other studies (O'Doherty et al., 2001; O'Doherty et al., 2003b; Small et al., 2001). Lateral OFC activation was in these studies found in response to punishing outcome, whereas medial OFC activation occurred in response to a rewarding outcome. These results suggest that the neural representations of reward and aversion are separated within these regions. Elliott and colleagues (2000) have also described a dissociation between medial and lateral OFC based on a review of functional neuroimaging studies. They suggest that the medial aspects of OFC is involved in monitoring and holding in mind reward values, whereas lateral OFC is recruited when a response previously associated with a reward has to be suppressed. Our results support this notion. Here, medial OFC, as discussed above, is active when subjects report increasing preference. Lateral OFC activity occurs when the label "Computer" is presented compared to the label "Louisiana". Thus, a plausible consequence of this response pattern is that

subject finds “Computer” labels less rewarding and more punishing than “Louisiana” labelled blocks.

In conclusion, cognitive input such as semantic word labels can have a profound influence on the aesthetic ratings of abstract artworks, by modulating brain regions such as medial OFC and frontal pole. Furthermore we have shown a dissociation of ventral striatum and medial OFC where the former may be involved in reward expectation and the latter region involved in representing stimulus affective value.

PART 5

GENERAL
DISCUSSION &
CONCLUSIONS

5.1 The modularity of aesthetic processing and perception in the human brain

The historical survey in this thesis was designed to provide a theoretical and contextual background in light of which the reasoning and motivation that guided the approach to these studies of neuroaesthetics might be fully understood. Having established the history of functional specialisation in the visual brain (section 2.1), the genealogy of the discipline from philosophical aesthetics (section 2.2), and human behavioural measures of aesthetic perception in the empirical aesthetics section (section 2.3) was outlined. Neuroanatomical sites at which information concerning reward and primary reinforcers are located to support and provide evidence concerning behavioural motivation were then proposed, based on the findings of electrophysiology in the primate (section 2.4), human non-invasive neuroimaging studies (section 2.5) and human neurological lesion studies (section 2.6).

In the discussion sections of each experiment the most important principles that are broadly applicable to the interpretation of these findings were discussed in order to set the appropriate context for distinguishing between confirmation, contradiction and extension of prior knowledge pertaining to aesthetic perception and processing as it is currently understood. In this section I will try to draw these findings together to form a tentative neuroanatomical model detailing the essential nodes through which aesthetic judgment is achieved in the human brain.

5.1.1 Subjective pleasantness

All animals constantly make decisions in order to survive, but perhaps only humans can evaluate and directly report the subjective pleasantness associated with this process. This hedonic experience is related to subjective experience, *qualia*, which has been described as ‘the hard problem’ of consciousness and which some philosophers believe will never be amenable to scientific analysis. But, the reported neuroimaging studies of the hedonic processes that are associated with aesthetic judgments suggest that this line of scientific inquiry

might yield important insights into the core of subjective experience specifically in terms of the modularity of aesthetic processing and perception in the human brain.

In order to pursue the question of where in the brain subjective experience of aesthetics is processed, we designed three fMRI paradigms in which the BOLD response could be compared in the context of subjective aesthetic judgments.

The stimuli were carefully chosen to investigate the different visual modalities of aesthetic judgments. In experiment 1 we used photographs of objects in normal contexts and objects manipulated into very abnormal contextual settings, whereas in experiment 2 we used achromatic photographs of architecture and human faces. In experiment 3 we selected non-canonical abstract artworks. Furthermore we applied different temporal strategies in the experiments such that subjects were given a short, or long period of consideration to reach an aesthetic judgment. All studies sought the neural correlates of aesthetic judgment, but used slightly different approaches to reach this goal. In experiment 1 and 2 subjects were presented with stimuli for 3000ms in order to maximise the number of different stimuli to which they were exposed, whilst in experiment 3, stimuli were presented for 5000ms. The use of longer duration exposure times was in fact primarily motivated by the consideration that longer exposure time might affect the evaluation process and thus the brain regions involved. Despite these differences in stimulus selection and stimulus presentation trials we found significantly more activity in the medial OFC in response to parametrical increasing aesthetic judgment paradigms in all three experiments. Thus the unified finding in this thesis is that medial OFC seems to be the essential nexus in the formation of aesthetic judgment.

5.1.2 Representation of stimulus reward value. Role of orbitofrontal cortex

As reviewed in the historical survey (section 2.4) electrophysiological studies in non-human primates implicate one component of the reward network in

particular in coding for stimulus reward value: orbitofrontal cortex (OFC). Human neuroimaging studies as reviewed in section 2.5 have confirmed a role for human OFC in coding stimulus value from a variety of sensory modalities, including taste (Small et al., 2002), olfaction (Gottfried et al., 2002; Rolls et al., 2003; Anderson et al., 2003), auditory (Blood et al., 1999) and vision (Aharon et al., 2001; O'Doherty et al., 2003b; Kawabata and Zeki, 2004) as well as for more abstract rewards such as money (Elliott et al., 2003).

In most of these studies the approach has been to compare medial OFC activity elicited by an affectively pleasant stimulus with that activity elicited by an affectively neutral stimulus and an affectively unpleasant stimulus. This leaves open the possibility that such effects are related to differences in sensory properties of the stimuli and not their reward value per se.

A different approach was applied in experiment 3 where the same stimulus was presented with two different word labels across subjects. Medial OFC responses tracked the reward value of the two conditions; stimuli rated aesthetically pleasing in one condition ("Louisiana" label) lead to an increase in medial OFC but activity in medial OFC to stimuli rated aesthetically pleasing in the other condition ("Computer" label) lead to a relative decrease (compared to the first condition, i.e. "Louisiana" labelled condition). Given that the experiment involved comparing the same stimuli but with different labels, so that the sensory properties of the stimulus are identical but only the reward value changed, this result provide very strong evidence for a role of human OFC in coding rewarding rather than sensory aspects of a stimulus.

The result of experiment 3 furthermore extends previous knowledge of OFC function in the sense that medial OFC can be modulated as a function of a cognitive label of an otherwise homogeneous stimulus material. As such it is subjects' conception of the stimulus (i.e. labelling) rather than the sensory properties of the stimulus that determine its hedonic or aesthetic value.

The role of the medial OFC in stimulus reward value was further validated in experiment 2 where we showed that medial OFC is modulated as a function of expertise. We showed identical stimulus material to two subject

groups, experts and non-experts, and thus the sensory properties of the stimulus material was balanced, but only the level of expertise changed between the two groups. We found that this modulation was coded in medial OFC for experts, and a relative decrease compared to experts was seen in medial OFC for non-experts.

Contrary to the finding that medial OFC code for stimulus reward value we found in experiments 1 and 3 that more lateral regions of the OFC code for a decrease in reward value. In experiment 1 we showed a correlation between decreasing aesthetic judgments and lateral OFC. And in experiment 3 we found that lateral OFC was engaged when subtracting “Computer” trials from “Louisiana” trials irrespective of the actual aesthetic rating given. This latter finding suggests that the lateral OFC is engaged due to the difference in reward value between the two labels.

These results provide some indication of a differentiation in function between medial versus lateral areas of the human OFC. This can be interpreted as evidence for a difference between medial OFC involved in decoding and monitoring the reward value, and lateral regions involved in evaluating punishers which when detected leads to a change in current behaviour. This dissociation may not apply for all types of reward, as pleasant gustatory stimuli have been found to activate lateral OFC (O’Doherty et al., 2002). Obviously it is dangerous to over-interpret these mere correlations with the elusive qualities of subjective experience, and so it would be interesting to obtain more evidence on this medial-lateral distinction by investigating patients with selective lesions to these areas as to whether their subjective affective experiences have indeed changed.

However, the proposed link to subjective hedonic processing in the results obtained here makes the orbitofrontal cortex an important gateway to subjective conscious experience. The OFC could be viewed as having the role of evaluating the affective valence of stimuli. The reward value of a stimulus is assigned in anterior parts of the OFC, where it can be modulated by hunger and other internal states (as reviewed in section 2.4.3), and can be used to influence subsequent behaviour, and made available for subjective hedonic experience. An

aesthetic experience does not necessarily have a particular effect on our welfare and internal need state, (as in contrast to primary rewards), but our results suggest that these different types of reinforcers such as aesthetic and hedonic experiences are coded in the OFC. However, as the OFC is a highly heterogeneous brain region, future neuroimaging and neuropsychological studies are likely to find more functional distinctions between its constituent parts.

5.1.3 Multiple reward signals in the brain

Most animals including humans have a propensity to seek out rewards and avoid punishments. Central to the organization of such behaviour is the ability to represent the value of rewarding and punishing stimuli, establish predictions of when and where such rewards and punishments will occur and use those predictions to form the basis of decisions that guide behaviour. In the results obtained in this thesis I have argued that stimulus reward value is represented in the medial OFC and more lateral aspects of the OFC. However, in addition to respond to rewarding stimuli once they have occurred, it is advantageous to be able to predict in advance when and where such rewards or punishments will occur so that behaviour can be organised accordingly.

In experiment 2 we found activity in ventral striatum, specifically nucleus accumbens, in a non-linear parametric expansion of the aesthetic judgment ratings. By using non-linear parametric expansions of our variables of interest we were able to make strong inferences about the underlying neural relationship. Where linear associations were significant we could be more confident that they reflected linear relationships than in previous studies using parametric designs where 2nd order relationships were not modelled.

In experiment 3 we also observed activity in ventral striatum, specifically lentiform nucleus. The observation of greater activity in ventral striatum under “Louisiana” than “Computer” conditions was found using a zero-order parametric expansion that reflect inferences made according to the two

labels or conditions irrespective of the actual aesthetic rating given. These findings can be accounted for by the hypothesis that ventral striatum responses signal prediction of reward and reward expectancy (Montague et al., 1996; Schultz et al., 1997; Berns et al., 2001).

Single unit studies in non-human primates implicate the phasic activity of dopamine neurons as a possible neural substrate of the prediction error signal (Schultz et al., 1997). The characteristics of this signal are reviewed elsewhere (section 2.4). Briefly, over the course of learning the signal shifts its responses from the reward to the predictor of reward (conditioned stimulus or CS). Unexpected omission of reward results in a decrease in activity from baseline (a negative prediction error), whereas unexpected presentation of reward results in an increase in activity (positive prediction error).

Human neuroimaging studies of reward report prediction error signals in areas to which dopamine neurons project, namely ventral striatum (O'Doherty et al., 2003a; McClure et al., 2003). These functional magnetic resonance imaging (fMRI) signal changes might reflect an interaction of intrinsic processing in those regions with the phasic activity of afferent dopamine neurons. Indeed, dopamine release has been reported in the striatum during reward prediction using positron emission tomography (PET) (Zald et al., 2004).

5.1.4 Salience versus reward in ventral striatum

Recently it has been proposed that the striatum is involved in coding stimulus saliency rather than having an exclusive role in reward processing per se (Zink et al., 2003). A similar proposal has previously been made to account for dopamine function (Horvitz et al., 2000). With regard to the striatum, this argument is supported by studies in which striatal activity is reported to 'non-rewarding' salient events such as presentation of infrequent distractor stimuli, as well as during an active reward task in which subjects must respond to obtain reward, compared with a passive task in which no response is required for reward (Zink et al., 2003; Zink et al., 2004). A key issue in the reward specificity versus

salience debate for dopamine neurons is whether or not such neurons also respond to equally salient punishing events. Indeed, there is strong evidence to implicate the ventral striatum in aversive as well as reward processing, especially during pain or anticipation of pain (Becerra et al., 2001; Jensen et al., 2003). This does not necessarily imply an exclusive role for striatum in affective processing, nor does it rule out a role for striatum in saliency coding. It remains possible that both types of process co-exist within the structure, given the heterogeneous response profile of striatal neurons at the single neuron level (Schultz et al., 2003). And thus our finding of involvement of ventral striatum in experiment 2 and experiment 3 cannot distinguish between these two alternative theories.

Based on our results important stages of reward processing have been identified and roughly localized in the brain in the course of the three fMRI experiment in this thesis that in a very tentative model emerges as the following: The occurrence of a visual rewarding stimulus, may trigger a learning signal in the ventral striatum so that the reward may become better predicted in the future (formation of stimulus-reward association). The value of the reward may then be assessed in the OFC, to be used to decide a course of action consistent with current goals. This is a very tentative description and is almost certainly incorrect in important ways. Nevertheless, the experiment in this thesis has provided evidence in support of this general view, which speaks directly to the power of this technique. The important point conveyed here is that a predictive stimulus seems to access distinct neural representations as those elicited by stimulus affective value. The evidence obtained in these present experiments suggests that the ventral striatum is involved in reward expectation, rather than being involved in affective responses to reward itself. OFC on the other hand is in the present experiments involved in representing stimulus affective value.

5.2 Conclusions

These neuroaesthetic studies were designed to expand our knowledge of the neurobiology of human hedonic experience in terms of aesthetic judgments. The domain of *motivation* has been thought to be an area of neuroscience concerned with internal need states rather than with the processing of sensory information. But the representation of something that gives pleasure when it is looked at, can be linked to the same neuronal mechanism that regulate the motivational state of an organism, thus connecting motivation to visual aesthetic inputs.

In experiment 1 we used functional magnetic resonance imaging to measure brain activity when subjects perceived objects in normal contextual settings compared to when the same object is perceived in an abnormal contextual setting. We were interested in exploring if brain areas activated when perceiving objects in normal conditions are also recruited when perceiving objects that are liberated from their expected and semantic context. We found a difference in neural activity when objects are perceived in normal context as opposed to objects perceived in abnormal context. More specifically these differences are reflected in engagement of frontal areas when a conflict between object and context occurs and engagement of LOC and parahippocampal areas when objects are presented in normal context. The results of the aesthetic judgment task revealed a medial-lateral trend in OFC that is likely to reflect a general response mechanism to evaluative judgments. The present study allowed us to draw an interesting bridge between visual perception and artistic representation. Indeed, the perceptual phenomena that we have studied from a neural point of view is not unlike the one that surrealist artists have uncovered in their attempts to represent visual scenes that liberated attributes such as objects from their expected semantic context.

In experiment 2 we developed a specific experimental hypothesis to investigate a possible modulation in OFC (and other brain regions) as a function of aesthetic expertise. In the first study we recruited subjects with no or little training in the arts. In the second study we engaged subjects with an expert-knowledge in architecture and subjects with no training in architecture to accommodate our main question of interest; is there any dissociation, in neural terms, between experts and non-experts reflected by aesthetic judgments of architecture?

Our results demonstrated an interesting separation in the brain response to subjective reports of preference (aesthetic judgment) that conformed to a difference between the two subject groups for buildings in brain areas traditionally associated with reward processing of stimulus pleasure in medial OFC and ACC.

Furthermore our model allowed us to distinguish between regions in which the responses scaled proximally to a non-linear (U-shaped) response profile across the range of aesthetic ratings. For this response profile we did not observe dissociations between the groups. A conjunction formally confirmed a significant U-shaped response profile in left nucleus accumbens and left anterior thalamus for the two groups.

The main result of this study indicate that separate reward regions, involved with stimulus pleasure are differentially engaged as a function of expertise, but that nucleus accumbens is equally activated in the two groups, and thus seems to be a general response mechanism to salient stimuli that is not modulated by expertise.

In experiment 3 we further pursued a modulation of the cortical and subcortical regions involved in aesthetic judgment as established in the first and second study. Similar to the first study we recruited a homogeneous group of subjects; however we manipulated a semantic cue accompanying the presentation of a homogeneous stimulus material consisting of original abstract paintings. Thus

the aim of this study was to measure the effects of semantic information ('real art' vs. 'fake art') on the neural responses to aesthetic judgments.

We found that the medial OFC respond in a linear fashion to increasing aesthetic ratings for abstract artworks labelled as "Louisiana" compared to conditions labelled as "Computer". Furthermore we found that lateral aspects of the OFC respond significantly more to "Computer" labelled conditions than when the label is "Louisiana", while we for the opposite contrast [L – C] found activation in ventral striatum.

A tentative model that accounts for these findings was proposed such that stimulus reward value are represented separately in OFC, with positive reward (increasing aesthetic judgments) being represented in medial OFC and negative reward value or punishments being represented in lateral OFC. Furthermore ventral striatum encode reward expectancy and the predictive value of a stimulus. Our main finding confirms previous studies of reward processing by providing further evidence that separate reward regions, involved with stimulus pleasure, are differentially engaged as a function of aesthetic judgments.

These findings expand previous studies that have used primary rewards such as food to implicate that the same neural reward mechanism and neuroanatomical structures are engaged when making aesthetic judgments of visual stimulus materials.

PART 6

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